МІНІСТЕРСТВО ОСВІТИ І НАУКИ, МОЛОДІ ТА СПОРТУ УКРАЇНИ

НАЦІОНАЛЬНИЙ ЛІСОТЕХНІЧНИЙ УНІВЕРСИТЕТ УКРАЇНИ

ЛІСОВЕ ГОСПОДАРСТВО, ЛІСОВА, ПАПЕРОВА І ДЕРЕВООБРОБНА ПРОМИСЛОВІСТЬ

Forestry, Forest, Paper and Woodworking Industry

МІЖВІДОМЧИЙ НАУКОВО-ТЕХНІЧНИЙ ЗБІРНИК

Виходить з 1964 р.

ВИПУСК 38

Львів – 2012

УДК 691.11
Лісове господарство, лісова, паперова і деревообробна промисловість : міжвідомчий науково-технічний збірник. – Львів: НЛТУ України. – 2012, вип. 38. – 188 с.

Рекомендовано до друку Вченою Радою НЛТУ України
(протокол №10 від 27.12.12 р.).

У статтях збірника містяться матеріали наукових досліджень і проектно-конструкторських робіт, спрямованих на вдосконалення технології та техніки лісового господарства, лісової, паперової, деревообробної промисловості та економіки.

Збірних розрахований на наукових, інженерно-технічних працівників, а також студентів, які виявляють інтерес до наукової діяльності.

Збірник підготовлено Національним лісотехнічним університетом України.

Адреса університету: 79057, м. Львів-57, вул. Ген. Чупринки, 103
Адреса редакції : 79057, м. Львів-57, вул. Залізняка, 11
тел. : (032) 238-44-96, 238-45-04;
моб. : 067-79-12-522;
факс : (032) 238-44-96;
e-mail: gaida@e-mail.ua
e-mail: f-wood-ind@ukr.net;
e-mail: vmmax@ukr.net;
http://www.FFPWI.NLTU.edu.ua

ЗМІСТ

UDC 630.182.4
Prof. V.I. Vaidanytch; prof. A.M. Deyneka; prof. S.I. Myklush; assoc. prof. N.D. Dovha; senior teacher T.V. Vaidanytch – UNFU

APPLICATION OF QUANTUM APPROACH IN DETERMINING CARBON SINK, DEPOSITED CARBON AND STAND-PRODUCED OXYGEN

The quantitative method of determining masses of carbon sink, deposited (sequestered) carbon and oxygen produced by stand as a result of photosynthesis is proposed. It is found that these masses are linearly dependent on the amount of solar radiation energy that came to forest for the corresponding period during the vegetation. The amount of carbon sink calculated by this method for the Lviv region forests is by far greater than the actual amount of industrial carbon dioxide emissions per year for this region.

Keywords: carbon sink, deposited (sequestered) carbon, oxygen produced by stands, phytomass, solar radiation energy, quanta of solar radiation energy, temperature of plants' vegetation.

One of the most pressing ecological problems facing humanity is global climate change. The reasons for this change are dynamic processes on Earth such as fluctuations in solar radiation intensity, human activities and other factors. Burning of non-renewable fossil fuels (coal, oil, gas), deforestation, forest fires, transport exhaust fumes etc. are the basic components of human activities that stipulate increase of greenhouse gases emissions, primarily carbon dioxide. The amounts of industrial emissions, including greenhouse gases, is registered reliably. The progress is not nearly the same as to recording the amount of harmful compound emissions and their long-term removal from cycling in the environment.

During their vital activity, forests accumulate carbon in the form of phytomass. Therefore, forest provides a long-term preservation (deposit) of carbon. In addition to phytomass, forests produce and release oxygen into the environment. Due consideration of the ability of tree stands to produce oxygen is important for predicting the amounts of oxygen used by various branches of industry, e.g. aviation, space technology etc.

The paper presents a quantitative method for determining the masses of photosynthetically bound atmospheric carbon dioxide, deposited (sequestered) carbon and oxygen released as a result of photosynthesis in a single cycle whose main parameter which characterizes the process of photosynthesis being the energy of solar radiation. Notice that the absorption of carbon dioxide from the atmosphere is called "carbon sink".

Determination of carbon sink. According to the Intergovernmental Panel on Climate Change (IPCC1 2007), the CO_2 concentration in the atmosphere amounted to 0.0379 % in 2005, while during the pre-industrial period it was 0.0280 % and has been increasing by 0.0002 % per year [1]. There has been a violation of the biosphere carbon cycle: income of carbon dioxide in the atmosphere began to exceed consumption by living organisms. It should be noted that such an assessment of this value has usually an indirect character. To do this, initially the mass of deposited carbon is determined, and after that sink is calculated by the molar mass [2, 3].

In order to make a direct quantitative evaluation of carbon sink, consider the general equation for photosynthesis which, per one mole, takes the form [4]:

$$CO_2 + H_2O + \underset{\textit{plant chlorophyll}}{\underline{\qquad h\nu \qquad}} \rightarrow C(H_2O) + O_2 \qquad (1)$$

The proposed method is based on a comparison of the input (CO_2 molecules) and output (fragments of molecules $C(H_2O)$) components on the one hand, and the energy of quanta (photons) of solar radiation, on the other hand, that are needed for the photosynthesis reaction (Eq. (1)). The input and output products are the only single chain and, therefore, the same photons are involved for converting the carbon dioxide molecule into the fragment of cellulose molecule in the process of photosynthesis. So for the purpose of defining mass of carbon sink approach of determining yield of phytomass by energy photosynthetic active solar radiation is used (PASR) [5, 6, 7].

According to [8, p.593], an average of 10 photons are used to form one molecule of oxygen in the Eq. (1). Obviously, these photons are primarily used to bind molecules of photosynthetic carbon dioxide. Taking into consideration that it is a unitary process, the amount of 10 photons will be preconditioned for binding CO_2 molecules as well.

The number of bound carbon dioxide molecules N_{mol}, as well as that of $C(H_2O)$ molecules produced through photosynthesis will amount to:

$$N_{mol}=N_{ф}\cdot B, \qquad (2)$$

where: $N_ф$ – amount of photons packets (10 photons in one packet) which are involved in binding carbon dioxide molecules, B – coefficient that determines quantum efficiency of photosynthesis processes.

The mass of carbon sink M_{BC} is defined by a relation:

$$M_{BC} = \frac{\mu_B \cdot N_{mol}}{N_A} = \frac{\mu_B \cdot N_ф \cdot B}{N_A}, \qquad (3)$$

where: μ_B – the molar mass of carbon dioxide; N_A – Avogadro's constant.

The amount of photon packets that are involved in photosynthesis is determined by the coefficient of photon utilization in the packet: $N_ф = N'_ф / f$,
where: $N_ф$ – total amount of photons energy of solar radiation; f – coefficient of spent quanta which determines amount of photons of one package that is required for the binding one CO_2 molecule. According to the definition f = 10.

Chlorophyll absorbs sunlight energy in blue and red parts of the spectrum with maxima 440 and 660 nm. Therefore, the total amount of photons $N'_ф$ of solar energy radiation that reached the stand area is equal to: $N'_ф = \frac{W_в}{h(\nu_c+\nu_ч)}$,

respectively

$$N_ф = \frac{W_в}{h\cdot(\nu_c+\nu_ч)\cdot f} = \frac{W_в \cdot \lambda_c \cdot \lambda_ч}{h\cdot c\cdot(\lambda_c+\lambda_ч)\cdot f}, \qquad (4)$$

where: $W_в$ – the only PASR energy that reaches the stand and which corresponds to the average temperature of vegetation t_B; $t_B \geq 5\ ^0C$; ν_c i λ_c and $\nu_ч$ and $\lambda_ч$ – respectively the frequencies and waves' lengths of absorption by chlorophyll of blue and red light, c – speed of light; h – Planck's constant.

Finally, the equation for the mass of carbon sink can be written as:

$$M_{BC} = \frac{\mu_B \cdot B \cdot \lambda_C \cdot \lambda_ч}{h\cdot c(\lambda_C+\lambda_ч)\cdot f\cdot N_A} \cdot W_B = A_{BC} \cdot W_B, \qquad (5)$$

where $A_{BC} = \frac{\mu_B \cdot B \cdot \lambda_C \cdot \lambda_ч}{h\cdot c(\lambda_C+\lambda_ч)\cdot f\cdot N_A}$ – constant for the selected forest type for which the coefficient B remains unchanged.

By introducing required values into the coefficient A_{BC}: μ_B = 0.044 kg / mol, B = 0.05 (since approximately 5 % of solar radiation is used in the process of photosynthesis [9, p. 302]), $\lambda_c = 440$ nm, $\lambda_ч = 660$ nm, h = 6. 626 $\cdot 10^{-34}$ J · s, c = $3 \cdot 10^8$ m/s, f = 10, $N_A = 6.02 \cdot 10^{23}$ mol^{-1}, the constant value for carbon sink is equal to: $A_{BC} = 0.485 \cdot 10^{-9}$ kg / j.

Determination of the mass of oxygen produced by stands in photosynthesis. The multistep and indirect method for determining the mass of stand-produced oxygen is well-known. It is based on the determination of phytomass increment. It is based on the quantitative and chemical composition of wood phytomass in a completely dry condition, the mass of all oxygen produced per year per 1 ha of forest area is calculated [10]. It is determined that for the formation of one ton of absolutely dry wood stands produce from 1.398 (for pine) to 1.423 t / ha (for aspen) of oxygen, its average value is equal to 1.4 t / ha [11].

This method, however, is labour-consuming. Its main shortcoming is determination of mass of photosynthetically produced oxygen, the main factor of photosynthetic process – solar radiation energy – is disregarded here.

The method we proposed is based, on the one hand, on the fact that during the process of photosynthesis, in parallel with the formation of the fragments of cellulose molecules ($C(H_2O)$) there also is produced an equal amount of oxygen molecules (O_2). On the other hand, the same quanta (photons) of sunlight are involved to create the end products of photosynthesis: ($C(H_2O)$) and (O_2). Thus, the mass of forest-produced oxygen as well as the phytomass are to be linearly dependent on the solar energy radiation that reaches the stand. Therefore, the problem is to find the number of oxygen molecules that are released during photosynthesis and then to compare them with the number of photons expressed in terms of the solar energy radiation. So to find the mass of oxygen released during photosynthesis, we will use the same approach discussed above for determining the mass of carbon sink and also the one proposed previously for determining stand phytomass through the mediation of solar energy radiation [5].

After the appropriate calculations, we will receive expression for the mass of photosynthetic oxygen produced by stands:

$$M_k = A_k \cdot W_в, \quad (6)$$

where $A_к = 0.353 \cdot 10^{-9}$ kg / j.

Finding the mass of carbon deposited by stands. There are two well-known methods for determining the mass of stand-deposited (stand-sequestered) carbon: a weight method [2, 3] and a chlorophyll method [12]. The method by weight is a multistage one and is based on determining increment of dry phytomass during vegetation or a longer period of the development of stands. The stand-deposited carbon, in turn, is calculated as rate of 0.5 for lignified and 0.45 for green plant parts of phytomass of organic substance in a completely dry condition [2, 17].

The chlorophyll method is based on determining the chlorophyll content in all organs of plants per unit area of the forested land (chlorophyll index) [12, 13]. Next step is calculating the amount of deposited carbon per unit of chlorophyll mass ((kg of carbon) / (kg of chlorophyll)). The obtained data as well as the molar mass are used to calculate the mass stand-deposited carbon.

To determine the mass of stand-deposited carbon, we will proceed from the fact that the end products of photosynthesis are both cellulose and oxygen; consequently, the phytomass will contain carbon which is derived from the previously absorbedcarbon dioxide. The mass of deposited carbon M_c, will be determined through the phytomass $M_ф$, and the molecular weights of cellulose molecule fragment and carbon dioxide:

$$M_c = \frac{\mu_c \cdot M_ф}{\mu_к} = A_c \cdot M_ф, \tag{7}$$

where: μ_c = 0.012 kg / mol – molecular weight of carbon; $\mu_к$ = 0.030 kg / mol – molecular weight of cellulose molecule fragment; $A_c = \mu_c / \mu_к$; $A_c = 0.4$.

By definition [5], the dry phytomass of closed stand is linearly dependent on PASR energy and amounts to:

$$M_ф = A_ф \cdot W_в, \tag{8}$$

where $A_ф = 0.331 \cdot 10^{-9}$ kg / j.

After substituting the last expression in the equation (7) we will be obtained an expression for the mass of deposited carbon:

$$M_c = A_c \cdot A_ф \cdot W_в = A_{сф} \cdot W_в, \tag{9}$$

where $A_{сф} = 0.132 \cdot 10^{-9}$ kg / j.

Thus, all the three examined parameters of photosynthesis considered above: the mass of carbon sink ($M_{вс}$), the mass of deposited carbon (M_c) and the mass of stand-produced oxygen ($M_к$) as well as previously determined phytomass ($M_ф$) [5-7], are linearly dependent on the main natural factor: the solar radiation energy ($W_в$) that reached the forest stand and which meets the requirements for plants vegetation conditions. This dependence will make it possible to automate the process of identifying these products of photosynthesis by the known energy of solar radiation. For this purpose, a flowchart presented in the works [14, 15] can be used while the constant coefficients $A_{вс}$, $A_к$ та $A_{сф}$ can be included in the computer software.

The flowchart that is used for measuring and calculating the above discussed parameters of photosynthesis includes a personal computer, a radiometer that measures the energy of solar radiation, an analogy-digital converter, and a temperature sensor. The data on solar radiation energy measured by the radiometer are transferred to the analogy-digital converter and thence to the personal computer. Simultaneously, the output from the temperature sensor is fed to the analogy-digital converter and thence to the PC. The computer software is set to record only that range of solar radiation energy of PASR $W_в$, which corresponds to the average daily temperature that is not below the temperature of plants vegetative stage (($t_в \geq 5$ ºC).

Thus, the inputs to the PC are the solar radiation energy $W_в$ and the average daily temperature. The simultaneous outputs from the PC, taking into account the constant coefficients $A_{вс}$, $A_{сф}$ and $A_к$, are the masses of carbon sink, deposited carbon and stand-produced oxygen. Note that the constant coefficients $A_{вс}$, $A_{сф}$ and A_K are found for full-stocked closed stands. Stands' condition, crowns density, completeness, site index, age, composition, stand density and other stand parameters are controlled by experimentally determined correlation coefficients $k_1, k_2, ..., k_n$. An important point is that the values of each of these coefficients for a particular site of stand are equal for all the measured masses: $M_к$, $M_ф$, $M_{вс}$ and M_c.

Table 1 contains comparative literature data on phytomass increment and stand-deposited carbon calculated by the weight- and chlorophyll methods (columns 5, 6) and by our method fo determining the masses $M_ф$, $M_{вс}$ and M_c by solar radiation energy (columns 8-10). One can see the correlation between the results obtained and the data from literature. Besides, column 9 contains data on the carbon sink mass which is not to be determined by traditional methods but is defined in the indirect way. Indicators of stand density, phytomass increments and carbon deposited by oak stands of Podillya, which are listed in the Table (columns 4-6), are averaged according to the results of the work [3, pp.140-160] over three sample plots for each given age group. Indicators of solar radiation energy $W_в$ (column 7) that meet the conditions of vegetative stage t ≥ 5°C, are listed according to [16, p.153]. Since the location of actinometric stations (AMS) may not coincide geographically with the analyzed region of stands, the solar radiation energy for each particular case was averaged over the nearest indices of the AMS'. In particular, the data on the energy for the Vologda region forests were taken from the Saint Petersburg AMS's, which is located almost on the same latitude; the value for the Podillya oak stands is the averaged data of the Kovel and the Berehove AMS's, and, finally, for forests of Volgograd region, the data were taken from the Volzhsky [16] near the city of Volgograd.

Table 1. Phytomass increment, carbon sink and stand-deposited carbon calculated by different methods

Region	Stand characteristics	Age, years	Density of stand, units / ha	by weight and chlorophyll methods		W_B, $t_в \geq 5°C$, J/(ha·year), x10[12]	by energy of solar radiation		
				average increment of phytomass, t / (ha • year)	deposited carbon, t / (ha • year)		phytomass increment, $M_ф$, t / (ha • year)	mass of carbon sink, M_{BC}, t / (ha • year)	mass of deposited carbon, Mф / (ha • year)
1	2	3	4	5	6	7	8	9	10
Komi Republic [13]	mixed pine stands, Orlov's site index- IV	90		1.33	1.7	10.68	3.54	5.18	1.41
Vologda [17]	mixed birch stands	70 62	1137 1304		1.70 1.34	11.10	3.67	5.38	1.47
Podillya [3, c.140-160]	pure beech stands, I[a]	30 40 50 60 70 80 average	1300 873 643 505 413 351	4.73 4.78 4.69 4.53 4.32 4.09 4.52	2.62 2.64 2.58 2.48 2.35 2.22 2.48	16.58	5.49	8.04	2.19
Volgograd [17]	mixed as-pen stands pure pine stands	35 74	1290 705		2.57 2.21	18.38	6.08	8.91	2.43

Table 2 presents the results of indirect determination of the mass of stand-produced oxygen according to literary sources (column 6) and by the proposed method of photosynthetic solar radiation energy (formula 6, column 7). By comparing these results, we can conclude that the values' for the mass of oxygen $M_к$, defined by our photosynthetic method are in the range from 4.42 to 5.91 t / ha and are sufficiently similarity with the literature [18, 19]. The difference in oxygen production between pine-beech stands and hornbeam-beech stands (column 6) may be due to incorrect application of a conversion coefficient – 1.4 that determines oxygen productivity in the stand [11].

According to our calculations, this coefficient does not exceed 1.07, as according to (6) $M_к = A_к \cdot W_в = (A_к\ M_ф)/\ A_ф = 1{,}07\ M_ф$. In addition, the results we obtained for the different stands are in close agreement and support the conclusion that the values for oxygen production for absolutely dry wood of different species are closely related [11].

It should be noted that calculated by the expressions (5), (6), (8) and (9) masses $M_{вс}$, $M_с$, $M_к$, $M_ф$ and presents solar radiation energy $W_В$ for all age groups and species within the same latitude are the same. The deviations of the values for these masses from the literature data, which can be observed in some cases, might be due to stand density and silviculture treatments (sanitary felling, thinning, etc.), that is why phytomass can be released from forest areas and cannot be recorded by conventional methods. On the other hand, higher literary values for the mass of deposited carbon as compared to those calculated by the expression (5), may indicate to rough application of the proposed coefficients values in converting phytomass into carbon (0.5 to trunk and 0.45 for leaves and needles) [2 , 17].

Table 2. Comparison of determining the mass of oxygen produced in different ways

Stands region	Stand, Orlov's site index	Age, years	$W_В$, $t_В \geq 5$ °C, J/(ha·year), X 10^{12}	Mass of produced oxygen ($M_к$), t/ha	
				according to literature	according to our method
1	2	3	4	5	6
Central zone of mixed forests [10]	birch, II	50	12.52 [11] (Smolensk)	4.00 [10]	4.42
The averaged data [9]			15.24 [11] (Kovel)	1.80 – 5.00 [9]	5.38
West Roztochya	Mixed pine and beech I-I[a]	50 100	16.75* "	19.3 [12] 9.0 [12]	5.91 "
South western part of Podillya	Mixed beech and hornbeam, I	50 100	17.35** "	14.5 [12] 7.5 [12]	612 "

* Energy of photosynthetic radiation $W_В$ is defined as average value between the energies of actinometric stations in Kyiv and Derkul (Luhansk region) [16].

** Energy of photosynthetic radiation $W_В$ is defined as average value between the energies of actinometric stations in Kyiv and Volzhsky [16].

Various authors [3, 13, 17] have repeatedly emphasized that the masses of carbon sink, deposited carbon (and hence mass of oxygen produced by stands) as well as phytomass are dependent on the stand composition, its age, stand density, density of crowns and many other factors. In order to take into account the impact of these factors, the correlation coefficients k_1, k_2, ..., k_i are introduced, the numerical values of which should be experimentally identified in advance and then installed in the computer program. It is important that the value of each of these coefficients for selected individual characteristics such as composition, age of stand, crowns density etc. are identical for all measured values $M_{вс}$, $M_с$, $M_к$ and $M_ф$.

By way of example, we present here the calculations of the masses of carbon sink ($M_{вс}$), deposited carbon ($M_с$) and photosynthetical stand-produced oxygen ($M_к$) for the Lviv region forests and then we compare the results obtain with actual emissions of the greenhouse gases. According to the Lviv Regional Administration of Forestry and Hunting Enterprise, the total forest area of Lviv region amounts to 693,000 ha [20]. Carbon dioxide emissions in Lviv region amounted to 2,268,669.496 t/year in 2008 [21].

To use these data for approximate comparative calculations, we can assume that these parameters have not changed significantly. In spite of the ununiform temperature conditions within Lviv region, due to the Carpathians where the main portion of the region's forests are concentrated, we will use the FAR energy value as an averaged parameter proposed for the Western Roztochya: $W_в = 16.75 \cdot 1012$ J / (ha · year) [15]. By using the expressions (5), (6) and (9), we will find the corresponding values:

$$- M_{вс} = A_{вс} \cdot W_в \cdot S = 5629759 \text{ t/year};$$
$$- M_c = A_{сф} \cdot W_в \cdot S = 1532223 \text{ t/year}; \quad (10)$$
$$- M_к = A_к \cdot W_в \cdot S = 4097536 \text{ t/year}.$$

The resulting value for carbon sink which can be provided by the Lviv region forests, even with low density (k = 0.5), exceeds the present amount of industrial emissions of this gas per year. The resulting figures do not include the contribution of parks, gardens, green plantations of the cities and towns, private fruit gardens, farmlands, meadows, pastures and other areas that are occupied by green plantations.

As a result of photosynthetic activity, 1,532,223 tons of carbon per year is deposited by the Lviv region forests in the form of biomass, thus being removed from the atmosphere. Litter layer is formed in the forest together with the increment of woody mass containing leaves, twigs etc., which can be decomposed within the period of half decay 0.75 (for leaves) and 4 years (for lignified parts) [22, s.125]. The litter makes up 1-5 % of the total mass of mature trees [22, s.110]. That is why the rate of deposited carbon for the decomposed litter is not significant and does not exceed 76,611 tons per year out of the total 1,532,223 tons. Accordingly, additional 281,488 t/year of carbon dioxide is released into the atmosphere and that is of small importance.

The next factor that can influence the amount of stand-deposited carbon is associated with plant breathing, especially in the dark period of day, when CO_2 only is released into the atmosphere. In the summer, at a temperature of 20 °C, deciduous tree species, due to dark respiration, emit 3-4 mg of CO_2 per hour per 1 g of dry substance, whereas conifer trees – only 1 mg [22, p.66]. Without going into details of the deciduous/conifers ratio in the region, we will take the 2.5 mg per 1 g of dry substance as the average rate of discharging CO_2 to dark respiration. To express it in terms of one year, this will make up about 5.25 g per 1 g of dry substance. The ratio (8): $M_ф = A_ф \cdot W_в \cdot S = 3.84 \cdot 10^6$ t/year is used to find the annual increment of phytomass (dry substance). Hence the mass of carbon dioxide emitted due to dark respiration of the stand is equal to $M_{т.} = 5.25 \cdot 10^{-3}$kg / kg • 3.84 • 10^6 t/year = 20.160 t/year, which does not have a significant impact on the amount of stand-deposited carbon.

Thus, the balance of carbon dioxide with regard to carbon sink, on the one hand, and industrial emissions, the litter decay and dark respiration, on the other hand, amounts to 3,264,319 t/year. Accordingly, the Lviv region forests area absorb 2,365,440 t/year of carbon dioxide from the atmosphere in addition to the present industrial emissions without increasing CO_2 concentration. In order to make the evaluation of the above-mentioned parameters more reliable, it is essential that a network of AMS should be developed and allocated in the most forested areas; also it is necessary that an appropriate software should be developed for them with consideration of the contribution from non-forested area: shrubbery, meadows, farmland and other vegetation-covered areas.

Finally, the Lviv region forests produce oxygen at a rate of 4,097,536 t/year as a result of photosynthetic reactions. On the basis of one hectare per day, the average amount makes up 28.2 kg/day, which correlates with the number of 25 kg/day according to [22, p.143]. In our calculations, the vegetation period is assumed to last 210 days.

Conclusions: 1. The proposed method can be used to determine the masses of carbon sink, deposited carbon, and stand-produced oxygen both in discrete and continuous regimes by means of known energy of solar radiation $W_в$ that came to forest stand for a given period of time. The application of direct and convenient method of determining the mass of carbon sink through quanta of solar radiation energy may prove to be an important tool for monitoring industrial CO_2 emissions.

2. The amount of carbon sink for the forests in Lviv region is almost twice as much as the present amount of industrial emissions of this gas per year. The difference is covered at the expense of carbon dioxide present in the atmosphere and additional industrial emissions from other less forested regions of Ukraine. It is important to note that almost all carbon component of the greenhouse gases is deposited by the Lviv region forests and, consequently, is removed from the long-term cycling thereby ensuring the conditions for the region's sustainable development.

3. There is a need to install the AMS network, particularly in the most forested regions, for the purpose of recording the amount of solar radiation energy and identifying the portion which meets the conditions for plant growth. It is also essential that appropriate computer software should be developed to ensure automated recording the carbon sink, deposited carbon and other parameters of photosyntyhesis.

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УДК 630.182.4 ***Проф. В.І. Вайданич, проф. А.М. Дейнека, проф. С.І. Миклуш, доц. Н.Д. Довга, ст. викл. Т.В. Вайданич – НЛТУ України***

Застосування квантового підходу для визначення фотосинтезованого вуглецевого стоку, депонованого вуглецю та продукованого деревостаном кисню

Запропонований кількісний метод визначення мас вуглецевого стоку, депонованого вуглецю та продукованого деревостаном за рахунок фотосинтезу кисню. Внаслідок фотосинтезу під впливом квантів видимого світла відбувається перетворення молекул вуглекислого газу та води у фрагмент молекули вуглеводу клітковини $C(H_2O)$ та кисню. На утворення однієї молекули кисню витрачається в середньому десять фотонів. Оскільки поглинання фотонів, зв'язування молекул вуглекислого газу, синтез молекул вуглеводів клітковини і продукування кисню є єдиним процесом, то виражаючи енергію сонячної радіації, що надходить за певний проміжок часу, через поглинуті хлорофілом фотони з сумарною енергією синього (440 нм) і червоного (660нм) світла, визначаємо кількість, а відтак і масу молекул кисню, зв'язаного деревостаном вуглекислого газу, приросту фітомаси, а з останньої і масу депонованого деревостаном вуглецю. Внаслідок проведених розрахунків, отримані співвідношення для розглядуваних величин:

$$M_{вс} = A_{вс} \cdot W_в, \quad \text{де } A_{вс} = 0{,}485 \cdot 10^{-9} \text{ кг/Дж};$$
$$M_с = A_{сф} \cdot W_в, \quad \text{де } A_{сф} = 0{,}132 \cdot 10^{-9} \text{ кг/Дж};$$
$$M_к = A_к \cdot W_в, \quad \text{де } A_к = 0{,}353 \cdot 10^{-9} \text{ кг/Дж},$$

де: $M_{вс}$ – маса вуглецевого стоку, $M_с$ – маса депонованого вуглецю, $M_к$ – маса продукованого деревостаном кисню, $W_в$ – енергія сонячної радіації, що відповідає середній температурі вегетації рослин $t_в$ ($t_в \geq 5$ °C); $A_{вс}$, $A_{сф}$ та $A_к$ – постійні коефіцієнти, виражені через довжини хвиль поглинання хлорофілом у синій і червоній ділянках оптичного спектра, сталу Планка, швидкість світла та інші величини.

Відтак, всі три розглянуті параметри фотосинтезу: маса вуглецевого стоку, маса депонованого вуглецю та продукованого деревостаном кисню лінійно залежать від основного природного чинника – енергії сонячної радіації ($W_в$), що надійшла на деревостан і відповідає умовам вегетації рослин. Така залежність дозволяє автоматизувати процес визначення цих продуктів фотосинтезу за відомою енергією сонячної радіації. Блок-схема для вимірювання і розрахунку розглянутих параметрів фотосинтезу містить персональний комп'ютер, радіометр для вимірювання енергії сонячної радіації, аналого-цифровий перетворювач, датчик температури. Виміряна радіометром енергія сонячної радіації передається на аналого-цифровий перетворювач, з якого поступає на персональний комп'ютер. Паралельно на аналого-цифровий перетворювач, а

з нього і на персональний комп'ютер, надходять покажчики датчика температури. Програма комп'ютера налаштована на реєстрування лише тієї енергії сонячної радіації $W_в$, яка відповідає середньодобовій температурі не нижче температури вегетації рослин ($t_{сер} \geq 5$ °C). Отже, на вхід персонального комп'ютера подається енергія сонячної радіації $W_в$ та середньодобова температура. На виході з персонального комп'ютера, з врахуванням постійних коефіцієнтів $A_{вс}$, $A_{сф}$ та $A_к$, отримуємо в синхронному режимі маси вуглецевого стоку, депонованого вуглецю та продукованого деревостаном кисню.

Зауважимо, що постійні $A_{вс}$, $A_{сф}$ та $A_к$ знайдені для повністю зімкнених деревостанів і з максимальним ступенем покриття. Стан зімкненості крон, ступінь покриття, повнота, бонітет, вік, склад, густота насаджень та інші параметри деревостану регулюються експериментально встановленими корелювальними коефіцієнтами k_1, k_2, …, k_n. Важливо, що значення кожного з цих коефіцієнтів для окремої вибраної ділянки деревостану однакові для усіх вимірюваних мас: $M_к$, $M_{вс}$ та M_c. Проведені розрахунки вуглецевого стоку, депонованого вуглецю та продукованого деревостанами Львівщини кисню запропонованим способом і зроблені порівняння отриманих величин з наявними промисловими викидами вуглекислого газу підприємствами цього регіону, які задовільно корелюють між собою. Показано, що величина вуглецевого стоку, яку спроможні забезпечити ліси Львівщини більш, ніж у два рази перевищує наявну масу промислових викидів цього газу за рік

UDC 630*81:630*64
Assoc. prof. ***I.M. Sopushynskyy – UNFU***

DIAGNOSTIC MODEL OF SYCAMORE (*ACER PSEUDOPLATANUS* L.) WITH WAVY-GRAINED WOOD GROWING IN THE UKRAINIAN CARPATHIAN FOREST STANDS

This article considers the forestry importance of sycamore wavy-grained wood. Altogether, 72 model trees of sycamore with wavy-grained and straight-grained wood were investigated in the forest stands with the relative stocking of 0.4-0.7 at the altitude from 750 to 1250 m. The diagnostic model for identification of the sycamore with wavy-grained wood was developed.
Keywords: wavy-grained wood, sycamore, diagnostic model, forest stand.

Introduction. The economic efficiency of forestry enterprises is a catalyst for socially and environmentally acceptable forest management. The profitability of forestry enterprises is one of the main goals of forest managers. Their main objectives are concentrated on silvicultural practical experience in increasing growth (site preparation, thinning, selection, fertilizing etc.) [2, 3, 8]. The price of wood can vary significantly due to the different economic factors such as fashion, demand, and substitutability. The key to success in the European timber market is through competitive pricing of wood material or wood products, that takes note of the specific characteristics of wood, and in particular its decorative and acoustic properties [2, 3, 6, 12].

Currently, the value of high-value decorative and acoustic sycamore wood is underemphasized in Ukraine. Wavy-grained sycamore wood is characterized by the unique color, grain and texture that give the appearance of undulating waves as they reflect light differently [6, 7, 10]. The abnormality of sycamore wood significantly increases its commercial appeal, but it has been hardly exploited in Ukrainian Carpathian, without exploring its forestry potential. The biological causes of the wavy-grained sycamore wood are still largely unknown, and scientific and practical recommendations for its diagnosis, care, conservation and forestry can provide great insight to the forest managers [4, 6, 8]. The economic value of decorative wood should correspond to its real market price. However, in Ukraine decorative wood is currently undervalued [2, 3]. Knowing the special features of decorative wood, foresters can manage stands with curly sycamore linking to the target consumers. Additionally, by discerning high-value decorative characteristics one could gain significant competitive advantage. For example, furniture, cabinet, moulding and millwork and other value-added manufacturing industries in Ukraine can take the opportunity to make advantage of the attribute findings. Increased utilization of the locally grown sycamore trees may result in profitability for the forestry and wood-processing enterprises [3, 6].

Biological and physical characteristics of sycamore wavy-grained wood and its distribution have not been subject of special study [2, 3]. The identification of this type of wood early in the forestry process allows better log value protection. There is a lack of peer-reviewed, scientific investigations of the silviculture of sycamore stands with wavy-grained wood. The main objectives of this study are to develop a diagnostic model for sycamore wavy-grained wood and to substantiate advice for the management related to the growing curly sycamore in the Ukrainian Carpathian forest.

Materials and methods. The study was conducted in the natural stands growing in the Ukrainian Carpathian Mountains. Silvicultural and dendrometrical characteristics of broadleaves forest stands were collected by field studies with focus on acquiring and in-depth understanding of sycamore with wavy-grained wood as well as its forestry potential. Altogether, 36 model trees of sycamore wavy-grained wood and 36 of sycamore straight-grained wood were studied for their morphological and silvicultural features, as well as anatomical and physical wood properties. Algorithmic approach makes it possible to systematize knowledge about differences in morphological, anatomical characteristics and physical properties of curly sycamore (Fig. 1).

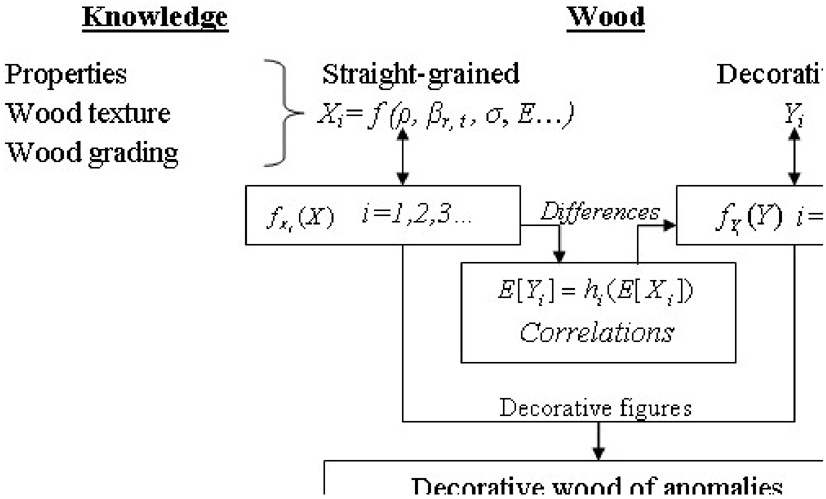

Fig. 1. Diagnostic algorithm of trees with decorative wood

The wood quality (X_i) is defined as a function of the wood properties related to density *(ρ, кг·м$^{-3}$)*, radial and tangential shrinkage *($\beta_{r,t}$)*, strength *(σ,Н·мм$^{-2}$)*, module of elasticity *(E, Н·мм$^{-2}$)* etc. Decorative wood *(Y_i)* is determined by the function of distinctive characteristics that emphasize dimensional texture of wood and acoustic properties. The results of the investigation can be linked directly back to the forest as preference data for wavy-grained wood can be applied in the forestry by forest managers.

Results. The biological feature of decorative wood is characterized by diversity and variation of properties within the trunk and is influenced by many factors [5, 6, 8]. The fundamental structure of wood, from the molecular to cellular or anatomical level, determines the properties and behaviour of wood [4, 9]. The forest stands are located at the altitude from 750 to 1250 m with the relative stocking of 0.4-0.7. The Table 1 below provides further biometric details of broadleaves stands with sycamore wavy-grained wood.

The conservation of forest stands with sycamore wavy-grained wood can help retain the future value of decorative wood by reducing undesired damage. Under certain conditions it may actually make more sense to preserve bio-groups of trees untouched near well-known sycamore wavy-grained wood, rather than partially harvesting them to remove the individual straight-grained wood. Therefore the diagnostic model of sycamore trees with wavy-grained wood plays a special forestry role (Fig. 2).

Table 1. Forestry potential of broadleaves stands with wavy-grained wood of sycamore

Index of forest type *	Alt., m	Stand composition**	B / P	M	Sycamore with wavy-grained wood					
					N	A	$h^{/}$	$d^{/}_{1,3\,m}$	$l_{an.wood}$	$M_{an.\,wood}$
D_3–fas-abaPia[a]	1000	8ACPS 2FAS +ABA[I]	I/0,60	350	1	106	31	42	5	0,61
C_3-acpsFas[b]	1050	6 FAS (190)2FAS (110) 2ACPS[II]	II/0,50	270	3	180…260	28…34	68…80	4…6	6,99
C_3-acpsFas[b]	1050	5FAS(170)2FAS (100)3ACPS[III]	II/0,70	380	1	170	27	52	4,5	0,97
C_3-acpsFas[b]	1120	7FAS(190)2FAS (100) 1ACPS[IV]	II/0,60	330	2	160…180	26…29	53…61	4…5	2,27
C_3-acpsFas[b]	1050	6FAS(200)2FAS (100)2ACPS+ABA[V]	II/0,60	320	4	150…180	27…29	51…64	4…6	5,02
D_3-pia-fasAba[c]	850	4FAS(170)3ACPS 2FAS (80)1ABA[VI]	I/0,60	320	1	150	29	43	5	0,68
D_3-abaFas[d]	880	3FAS(130)2ACPS 3FAS (75)2ACPS[VII]	I/0,55	340	11	74…108	25…31	38…81	3…12	18,19
C_3-acpsFas[b]	1250	10ACPS+FAS + PIA[VIII]	IV/0,40	159	3	150…170	21…24	51…66	3…5	2,83
C_3–fas-abaPia[e]	1100	5ACPS4PIA 1FAS+FRE[IX]	II/0,56	400	3	150…165	24…27	46…57	4…5	2,36
C_3-acpsFas[b]	1250	6ACPS4FAS +FRE[X]	V/0,40	81	2	120..140	21…22	38…43	4…5	1,01
C_3 -pia-abaFas[f]	750	8FAS2ACPS[XI]	I/0,70	270	2	110….120	28…29	40..46	5…8	1,71
C_3-acpsFas[b]	1240	7ACPS3FAS[XII]	III/0,50	210	3	100…150	22…24	30…49	3…4	1,60

Notes: *Alt. – altitude, m; B – stand quality; P – relative stocking; N –number of model trees, units·га$^{-1}$; A – age range of trees, years; $h^{/}$ – height range of trees, m; $d^{/}_{1,3m}$ – diameter range of trees at breast height, cm; $l_{an.wood}$ – length of wavy-grained trunk, m; M – wood stock, m^3·га$^{-1}$; $M_{an.wood}$ – anomaly wood stock, m^3·га$^{-1}$. Acer pseudoplatanus* L. *– ACPS; Fagus sylvatica* L.*- FAS; Abies alba* L. *– ABA; Picea abies* Karst. *– PIA; Fraxinus excelsior* L. *– FRE.*

***Index of forest type:** *a – wet mixed broadleaves (beech-fir-spruce) forest on the brown forest soil, b – wet broadleaves (sycamore-beech) forest, c – wet mixed broadleaves (spruce- beech-fir) forest, d – wet mixed broadleaves (fir – beech) forest, e – wet mixed broadleaves (beech-fir-spruce) forest on the acid brown forest soil, f – wet mixed broadleaves (spruce-fir – beech) forest.*

****Location:** *Velykobereznyy forestry enterprise, Lyuta forest district: I- compartment 3, survey unit 41; II – compartment 20, survey unit 2; III – compartment 10, survey unit 7; IV – compartment 30, survey unit 3; V – compartment 19, survey unit 1; VI – compartment 15, survey unit 36. VII – compartment 1, survey unit 27, Velykobereznyy forestry enterprise, Zhornava forest district. VIII – compartment 40, survey unit 30, Brusturyansk forestry-hunting enterprise, Playsk forest district. IX – compartment 28, survey unit 9, Mokryansk forestry-hunting enterprise, Bradulsk forest district. X – compartment 9, survey unit 5, Velykobychkiv forestry-hunting enterprise , Kosivsko-Polyansk forest district. XI – compartment 1, survey unit 8, Osmoloda forestry enterprise , Anhelsk forest district. XII – compartment 2, survey unit 23, Carpathian biosphere reserve*

The age range (A) of researched sycamore trees varied from 74 to 260 years. The best biotope for sycamore wavy-grained wood is located in between forest types D_3-abaFas[d] and C_3-acpsFas[b] at altitude of 880 m and 1050 m. Scientific observations have shown that the spring of the crown ($h^{/}_{crown}$) of curly sycamore started on the average height of 13 m and on 25 % less than of sycamore with straight-grained wood.

Based on the results of our scientific observations in the study area of growth and development of sycamore wavy-grained wood as well as its technical quality, we suggest that felling occurs for trees at the age of 120±5 years ($A_{felling}$). This is largely due to the particular characteristics of sycamore false heartwood formation and its destruction.

Sycamore

Straight-grained wood	Wavy-grained wood

GOST 9462-88, DSTU 2152-93, EN 350-2, DSTU EN 1315-1-2001, DSTU EN 1316-3: 2005, wood texture classification, grading class of decorative wood

Forest biotopes	
Within the nature growing area	C_3-acpsFas[b], C_3–fas-abaPia[e], D_3-abaFas[d], D_3-pia-fasAba[c], at altitude of 800 - 1100 m

Morphological features of trees	
A_{mature}=100…120 years h = 19…30…40 m h_{crown} = 14…17…20 m	A=74…137…260 years $h^{/}$ = 21…27…34 m $h^{/}_{crown}$ = 8…13…18 m, multiple top of tree $l_{an.wood}$= 3…5…12 m Bark: smooth until 60-80 years and after platy

Structural distinctions of wood	
d_{vessel} = 26... 74...133 μm N_{vessel} = 15…23…30 vessels·mm^{-2} N_{ray} = 3,0…4,9…7,9 rays·mm^{-1}	d_{vessel} = 24...62...100 μm N_{vessel} = 15…22…36 vessels·mm^{-2} N_{ray} = 5,3…7,3…9,6 rays·mm^{-1} λ = 2,9…7,6…11,1 mm $A_{wavy\text{-}grain}$ = 11…20 years

Physical properties of wood	
$S_{tree\ rings}$ = 0,5…2,1…6,5 mm ρ_{12} = 530...630...790 kg·m^{-3} ρ_{basic}= 471…516…573 kg·m^{-3} ρ_0= 545…595…657 kg·m^{-3} ρ_{green}= 816…871…993 kg·m^{-3} Shrinkage, %: β_t =7,1…9,3…10,8 β_r =3,0…4,1…5,6 β_v =11,1…13,2…15,0	$S_{tree\ rings}$ = 1,5...4,3...10,8 mm ρ_{12} = 570…609…640 kg·m^{-3} ρ_{basic}=481..503…532 kg·m^{-3} ρ_0= 549…575…620 kg·m^{-3} ρ_{green}= 912…1009…1068 kg·m^{-3} Shrinkage, %: β_t =6,6…7,7…8,7 β_r =4,0…4,6…5,6 β_v =11,8…13,6…14,3

Forestry practice	
- according to the project organization and development of forestry	- to provide independent forestry unit "sycamore sector with decorative wood" - to create a seed plantations linking to felling trees in the seed year in the latter of September ($A_{felling}$= 120±5 years) - to set up a vegetative reproduction linking to felling of trees in the second half of July and microcloning - in the March or April

Note: *A_{mature} – maturity age, years; A – age, years; $A_{wavy\text{-}grain}$ – age of the development of wavy-grained wood; $A_{felling}$ – felling age, years; h – height, m; d_{vessel} – diameter of vessels, μm; N_{vessel} – number of vessels in 1 mm^2; N_{ray} – number of rays in 1 mm; λ – length of wavy-grain, mm; S_{rings} – tree-rings width, mm; ρ_{12} – wood density by moisture content 12 %; ρ_{basic} – basic wood density; ρ_0 – wood density by moisture content 0 %; ρ_{green} – wood density in growing tree; β_t and β_r, – linear shrinkage in radial and tangential direction; β_v – volumetric shrinkage.*

Fig. 2. Diagnostic model of sycamore with wavy-grained wood

Thus, sycamore wavy-grained wood starts to develop at the age of 11-20 years ($A_{wavy\text{-}grain}$) [4], and the false heartwood decays at the age about 100 years (A_{mature}). Clear-cutting forest stands is appropriate in the winter after the seminiferous year. This creates ideal conditions for the regeneration of the natural stands of the sycamore wavy-grained wood. It is appropriate to assign individual stands to a separated forestry unit "sycamore forestry unit with high-value decorative wood". Ideally, a self-sustaining seed plantation should be set up late in September, vegetative plantation – in the second half of July, and cloning – in the March or April. The diagnostic model in this paper considers the biotope, stand type, soil-site indexes and its silvicultural features, morphological distinctive characteristics of anomaly growing trees, wood structure and physical wood properties, and gives recommendations for its protection and reproduction. An important task is carrying out studies of acoustic properties of wavy-grained wood because of its microstructure and submicroscopic structure.

Conclusions. In this study, a diagnostic model for identification of the sycamore trees with wavy-grained wood was developed. The purpose of the model is to aid foresters in improving silvicultural strategies. The research extends the information applicable to current daily and local experience in subject area of the effective use, conservation and reproduction of sycamore trees with wavy-grained wood in Ukraine. From the economical and environmental point of view, sycamore trees with wavy-grained wood play an important role in forestry and wood processing, and we recommend carrying out felling trees at the age of 120±5 years. Filling the gaps in the assessment of sycamore decorative wood could contribute to the improved management of forests across Europe. Hence, sycamore has significant potential for forestry, and its use as a timber resource should be promoted.

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УДК 630*811:630*64 *Доц. І.М. Сопушинський, канд. с.-г. наук – НЛТУ України*

Діагностична модель явора (*Acer pseudoplatanus* L.) із хвилясто-завилькуватою деревиною, що зростає в лісових деревостанах Українських Карпатах

Розглянуто лісогосподарське значення хвилясто-завилькуватої деревини явора. Досліджено 72 моделі явора з хвилясто-завилькуватою та прямоволокнистою деревиною у деревостанах з відносною повнотою 0,4-0,7 на висоті від 750 до 1250 м. Розроблено діагностичну модель явора із хвилясто-завилькуватою деревиною.

Ключові слова: хвилясто-завилькувата деревина, явір, діагностична модель, деревостан.

UDC 630*622+630*116.28+630*111

Prof. L.I. Kopiy; assist. S.L. Kopiy; assist. V.V. Lentiakov; senior teacher O.A. Chaplyk – UNFU

THE WAYS OF NATURAL REGENERATION OF OAK STANDS IN THE WESTERN FOREST-STEPPE OF UKRAINE

The present paper deals with the analysis of silvicultural treatment effects on fruiting, emergence of common oak advance regeneration, the dynamics of its mortality, changes in mycological structure, and re-distribution of nutrients across the soil profile. The peculiarities of common oak advance regeneration were investigated at the experimental sections of various thinning intensity. The study has revealed the relationship between the sunlight intensity and changes in biometrical indices of oak advance regeneration.

Keywords: natural regeneration, mycological structure, soil profile, oak, ecology, forestry.

According to the forest management zoning, our study region is situated in the western part of Ukraine, namely, in the Forest-steppe management district and partly in the Ukrainian Carpathians. For the purpose of our investigation, we chose oak stands typical for this region: west Ukraine's Forest-steppe and the Pre-Carpathian forest management districts within the territory of Lviv, Ternopil, and Khmelnytsk regions [5,6]. The study area is noted for its clearly discernible seasons. The longest winter (112 days) is found in the eastern parts, of shorter duration (103-104 days) – in the western parts. 75% of the study region area is characterized by the average temperature ranging from 0 °C to – 5 °C. However, some years are characterized by considerable rises and drops in winter temperatures [6].

The period of time during which the temperature keeps above 5°C lasts for 201-210 days. It starts during the first decade of April and ends in the last decade of October; the period over which the average daily temperature is above 10°C lasts for 154 days. The relatively high values of the average monthly temperature, substantial amount of precipitation during the growing season, the solar radiation balance of over 40 Kj/cm^2- all these factors determine optimal environmental conditions for common oak growth in this region. The balance between the steady development of the oak biogeocoenoses with their natural seeding regeneration has been disrupted owing to the extensive use of artificial regeneration methods for oak forests renewal. This is accounted for by several reasons. The central problems are: (1) unreliability of the current methods for successful natural seeding regeneration, (2) good seed years occur at intervals of considerable duration, (3) the process of natural seeding regeneration in oak forests under various environmental conditions has not been adequately studied yet.

Forests stands with the participation of common oak are abundant in all forest zones of Ukraine (Polissia, Forest-steppe, steppe, the Carpathians), however, this species is especially common to the Forest-steppe and the Pre-Carpathians, it is in this region that a permanent study area and 34 trial plots were estabilished for the purpose of investigating the process of natural regeneration in oak forests as well as developing an adequate silvicultural treatment system to ensure this regeneration process. Investigations of growth pattern, development, the dynamics of self-sown seedlings numbers and growing-up of common oak trees under the forest canopy and in felled areas, were conducted on the oak forests in Lviv-, Ternopil-, and Khmelnytsk regions at the Lviv-, Radekhiv-, Sambir-, Kamianets-Podilsk-, and Yarmolynets state forestry enterprises.

The permanent study area (PSA) was estabilished in a 200-year-old hornbeam-oak forest stand, its species composition being 10 oak/10 hornbeam, stocking = 0.3, stock volume = 150 m^3/ha. The study area is situated in the Kornalovychi naturally demarcated area within the territory of the Dubliany forest district (compartment 2, subcompartment 2), state enterprise [SE] "Sambir Lisgosp" (Fig. 1).

The PSA is estabilished in a fertile site type of forest, the site type is D3, forest type – moist hornbeam oakery, soil type – gley forest grey deep soddy medium podzolic medium loam soil on ancient alluvium. According to plant-sociological zoning, the forests of the study area belong to the Drogobych – Stryi district of oak forests of the Pre-Carpathians which have been preserved in the Dniester basin; in terms of the phytocoenotic and age structure, these forests are valuable plant communities [6].

The choice of site for the PSA establishment was made on the basis of detailed forest inventory and forest typological surveys of oak stands in the Kornalovychi area by Vorobiov's procedure [5]. The PSA is located on the right bank of the river Dniester, occupying the plain part of the area, at an elevation of 283 m above sea level. The PSA was estabilished with the objective to substantiate the silvicultural treatment system designed for promoting natural seeding regeneration of common oak under the canopy of low-stocked hornbeam-oak old-growth stand.

At the same time, systematic investigations were conducted at the PSA in order to examine: (1) changes in species diversity of herbs and species composition of symbiotic fungi, (2) the peculiarities of radial increment changes in common oak model trees at the experiment sections, (3) common oak fruiting, (4) re-distribution of humus and chemical elements across the soil profile, (5) as well as changes in the soil acidity following a variely of harvest cutting.

In addition to the PSA, we set up a number of experimental plots within typical all-aged stands estabilished in the predominant types of forest of the study region. (fresh hornbeam oakery (D_2-r-D) and moist hornbeam oakery (D_3-r-D). The plots were designed to study growth patterns, development, structure formation of the oak stands as well as peculiarities of natural seeding regeneration under the stands' canopy.

The trial plots were installed in accordance with the procedures generally-accepted in forest inventory and forestry practices, the forest typological investigations were carried out by D.Vorobiov's procedure [5], revised by B.Ostapenko and Z.Gerushynsky [14]. The growing stock and other inventory indexes were determined by using standard regulatory information. The quantity of acorns was recorded at 25 permanent, uniformly distributed inventory plots measuring 2x2 m each, the plots were marked with pegs in all the trial plots and sections of the PSA, Later on, self-sown seedlings and andvance growth of oak and other tree species were regularly measured on these permanent inventory plots. At the same time at each section, the following study activities were conducted: determination of light intensity, measuring biometrical indexes of the self-sown seedlings and advance growth which emerged under various environmental conditions, measuring the air temperature and humidity as well as investigating the herbaceous vegetation influence on the development of the oak self-sown seedlings and advance growth.

The numbers of the self-sown seedlings and advance growth of common oak as well as associate tree species were recorded according to year classes: one-year old, 2-3 year old, 4-7 year old, and older than 7 years. A detailed analysis of the soil was made at each section of the 4-sectional permanent study area. For this purpose, soil samples were taken from each horizon of the soil profile according to the commonly accepted procedures for measuring physical-and-chemical indexes.

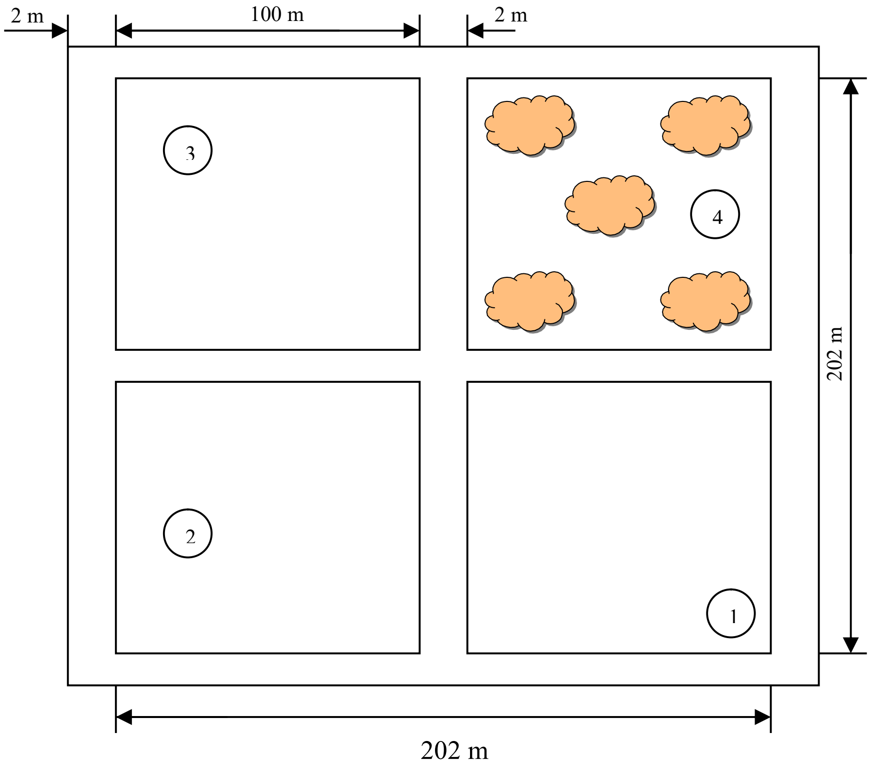

Fig. 1. Arrangement of the Kornalovychi permanent study area in the Dubliany forest district of SE " Sambir Lisgosp". Methods of felling: *1 – check section; 2 – clear cutting; 3 – uniform shelter wood felling in a series of two cuttings; 4 – group-selection felling in a series of three cuttings*

Among the stands where the trial plots were estabilished, analysed were hornbeam-oak stands of 25-200 years old. In particular, a 25-year old stand was analysed in the Lotatnytsi forest district of SE "Stryi Lisgosp", this stand was regenerated by seeding in 1982. The inventory characteristics indicate that the present stand is a highly-productive stand of site class Ia, stocking = 0.65, and stock volume = 99 m^3/ha.

On the whole, the share of stands analysed on the trial plots amounts to: (1) for the stands older than 100 years – 35 %, (2) for the stands of age 81-100 years – 32 %, (3) for the stands younger than 80 years – 33 %. The stands are characterized by a satisfactory health condition and rather a high level of productivity (Table 1). In order to study the effect of various methods of principal felling (clearcutting, uniform shelterwood felling in a series of two cuttings, group-selection felling in a series of three cuttings) on the dynamics of nutrient re-distribution as well as on the structural-and-functional soil condition, there was made an analysis of the soil following the first cutting (Fig. 2). In line with the results obtained it may be noted that at the sections where cutting of the understorey was made, the humus content decreased in all analysed horizons of the soil. The highest level of humus leaching (by 28.2 %) was observed in the soil layer of 0.0-10.0 cm deep at the section with clearcutting of hornbeam trees while the lowest level of leaching (11,1 %) was at the section with group-selection felling.

Table 1. The stands are characterized by a satisfactory health condition and rather high level of productivity

Sample plot №	Forest diatrict	Compa-rtment №	Subcor-patment №	Forest type	Stand composition	Species	Age, Years	Average diametre, Cm	Average Height, M	Stocking	Site Class	Grooving Stock, M3/ha
1	2	3	4	5	6	7	8	9	10		11	12
1	Naragiv	3	8	D_2-r-D	*9oac$_3$* *hoenbeam*	*oac$_3$* *hoenbeam* *Lime*	105 56 40	40.3 13.3 21.7	28.0 12.9 13.5	0.87	I	321
10	Pidgaitsi	22	3	D_2-r-D	*9oac$_3$* 1*hoenbeam*	*oac$_3$* *hoenbeam*	86 40	37.8 18.2	28.5 17.7	0.71	I	335
11	Pidgaitsi	21	4	D_2-r-D	*8oac$_3$* 2*hoenbeam*	*oac$_3$* *hoenbeam* *Lime*	86 76 80	35.3 23.8 41.4	25.8 19.8 25.1	0.78	I	315
14	Dubliany	2	2	D_2-r-D	*8oac$_3$* 2*hoenbeam*	*oac$_3$* *hoenbeam*	200 65	44.0 18.0	29.2 15.2	0.43	II	160
15	Chortkiv	76	1	D_2-r-D	*10oac$_3$* *+hoenbeam*	*oac$_3$* *hoenbeam*	110 50	54.6 16.0	32.9 14.8	0.53	I	307
20	Vinkivtsi	70	5	D_2-r-D	*6oac$_3$* 4*hoenbeam*	*oac$_3$* *hoenbeam* *Lime*	116 75 55	40.3 13.3 40.8	29.0 23.0 26.3	0.85	I	221
21	Vinkivtsi	73	1	D_2-r-D	*7oac$_3$* 3*hoenbeam*	*oac$_3$* *hoenbeam*	96	40.8 18.8	30.5 21.3	0.77	I	356

Humus accumulation was observed in the soil layer of 11.0-20.0 cm deep and 31.0-40.0 cm deep at the section with shelterwood felling of the understorey of the hornbeam-oak stand which had been formed with participation of common hornbeam.

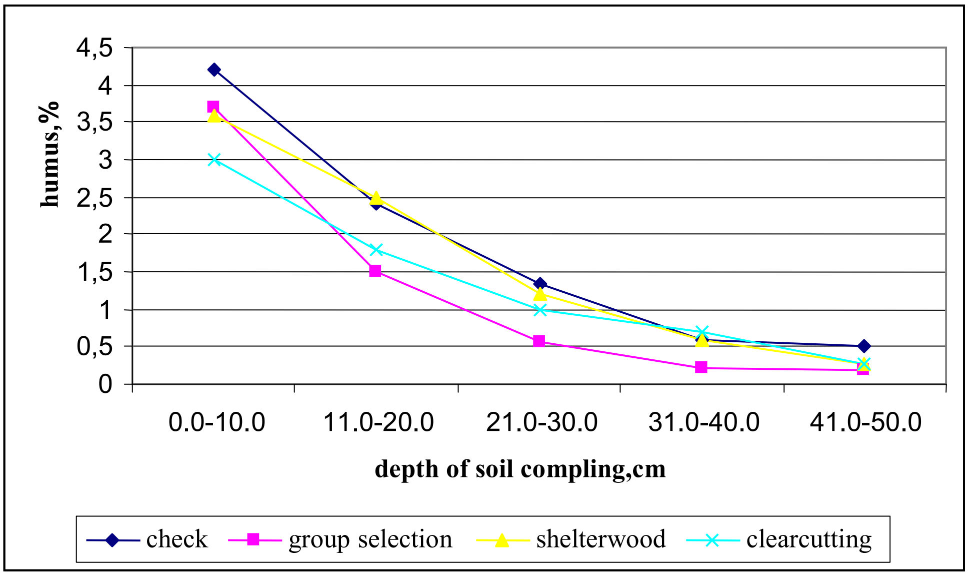

Fig. 2. Dynamics of humus content in the soil at the PSA sections following various methods of felling

A decrease in humus content in the analysed horizons was found at the section with clearcutting of hornbeam trees. Thus, in the 11.0-20.0 cm and the 21.0-30.0 cm layers, a certain build-up of humus was observed as compared with the dynamics of its re-distribution at the check section. As is seen from the data obtained, the soil of the check section in the old-growth stand has a maximum humus content (4.2%), which is characteristic of the upper 0.0-10.0 cm layer of the soil, the humus content gradually decreases up to a depth of 50 cm (0.5 %). Comparison studies of humus content changes depending on the method of felling used, show that the maximum humus content in the upper 0.0-10.0 cm layer of the soil corresponds to the check section while the minimum humus content corresponds to a clearcutting method. Humus content also decreases with other method of principal felling but less intensively compared to the clearcutting of subedificator: common hornbeam. Humus content in a 11.0-20.0 cm layer tends to decrease significantly at all the experimental sections but the decrease is most pronounced in the case of group-selection felling. In the case of shelterwood cutting, the change in the organic matter content is the least and it virtually does not differ from the check section values.

The overall assessment of humus content changes across the 0.0-50.0 cm soil profile shows that the lowest humus content is observed in the case of group-selection felling. It is interesting to note a peculiar feature of nitrogen accumulation in a 0.0-10.0 cm layer of the soil at all, without exception, sections where silviccultural treatments were conducted. The most significant increase in nitrogen content in the upper soil layer was recorded for the sections with group-selection felling of the understorey (by 29.9 %) and with clearcutting of the understorey(13.4 %). It is worth noting that nitrogen accumulation in a 21.0-30.0 cm soil layer was recorded for the section with clearcutting of the hornbeam trees. In all other cases a gradual decrease in nitrogen content was recorded for all analysed layers except for a depth of 31.0-50.0 cm at the sections with clearcutting and shelterwood cutting of the understorey. To make a thorough assessment of soil nutrient status of forest ecosystems at the study sections, the changes in the soil acidity-alkalinity balance were analysed, this balance is an important factor which regulates nutrient availability in the system soil-plant and controls the biotic activity of edaphotope. The value of pH salinity in the upper 0.0-10.0 cm layer of the soil polygon varies in the range from 3.6 to 4.1 units, the acidity level being the highest at the check section. The soil acidity decreases with distance from the surfrace, however, remaining high even up to a depth of 50.0 cm. As a result of thinning treatment of the understorey in the hornbeam-oak forest, formed with participation of common hornbeam, one can clearly observe a decrease in the soil acidity up to a depth of 30.0 cm (Fig. 3).

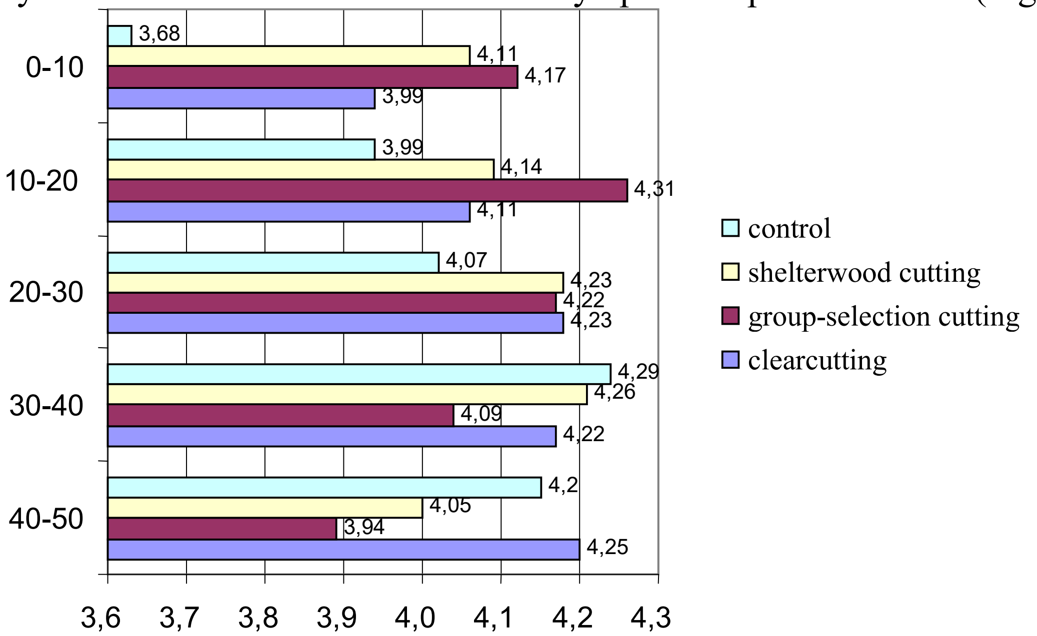

Fig. 3. Dynamics of the soil acidity (pH salinity) at the study area sections following various methods of felling

The intensity of the soil reaction (pH) decrease is inversely proportional to the degree of anthropogenic impact on the forest stands. The most significant reduction (by 16.7 %) of pH salinity value in the upper layer of the soil is observed in the case of group-selection felling, it is less pronounced (by 8.3 %) at the section with clearcutting of the understory. It is important to keep in mind that in the case of the pH value being about 4.0, the level of exchangeable aluminium rises to the concentration that is toxic for seed germination and development of fine roots in the organogenic zone; also this is responsible for unsatisfactory condition of self-sown oak seedlings that appear periodically under the dense canopy of old-growth oak stands. Further acidification of acid soils leads, along with releasing toxic aluminium, to the excess iron and magnesium ions which bind molybdenum into hardly-soluable forms.

The deficiency of freely-soluable forms of molybdenum causes disruption to the processes of nitrogen and carbohydrate exchange in plants, production of chlorophyll, absorption of calcium and phosphorus from the soil.

On this basis, it may be suggested that the soil acid reduction due to the application of silvicultural treatments would have a positive effect not only on the edaphotope functioning and the system "soil-plant" on the whole but this also could give rise to the occurence of considerable numbers of self-sown oak seedlings germinated from acorns previously released during good seed years.

In order to investigate the effects of various methods of principal felling on the mycological structure of the soil, we have examined changes in species composition of symbiotic fungi at the study area sections. Soil sampling was made at each of the four sections of the Kornalovychi permanent study area. As a result, we identified 35 species of fungi which belong to three classes (Zygomycetes, Ascomycetes, Deuteromycetes) and one family (Dematiaceae). It should be noted that the species composition of micromycelium fungi at the check section included 28 species whereas the section with clearcutting of the hornbeam-participating under storey revealed only 14 species. The soil samples from the check section show considerable species diversity among which are symbionts of fungi: mycorrhiza-forming fungi from the genera Penicillium (P. Jenseni, P. Cirylophilum, P. Luteum).

The analysis of species composition of micromycelium fungi at the other sections of the study area showed gradual loss of their species diversity on the plots where uniform shelter-wood and group-selection cuttings of the hornbeam-participating understorey were conducted. Our investigations revealed the fact that silvicultural treatments essentially impair the environmental conditions for growth and development of both mycorrhiza-forming and symbiont fungi. At the sections where shelterwood cutting of the hornbeam layer was made, the following fungi species are absent: Mortierella romanniana, Mucor silvaticus, Chaetomium globosum, Penicillium digitatum, Penicillium jenseni, Aspergillus candidus, Fusarium sambucinum and others that are commonly present at the check section and the section with group-selection felling of the hornbeam layer. Compared to the check section, the least marked difference in the species composition of micromycelium fungi was observed at the section with group-selection cutting of the understorey in the hornbeam-oak stand. It is significant that the soils which underwent essential man-induced load as a result of various kinds of principal felling, can support associations of micromycelium fungi that are capable of surviving under conditions of disturbed ecotopes (excessive drying-up, acidification, soil compactness).

It is worth noting that the plot with clearcutting of the understorey of the hornbeam-participating oak stand is lacking mycorrhiza-forming fungi, also the frequency indexes (q2) of species such as Phisopus nigricans, Penicillium ochro-chloron, Sclerotium sp., Phomopsis meliloti, Toruela herbarum, Humiculea grisea are essentially increasing, these species presence was minimal (or they were absent at all) at the check section. Most distinctly the negative effect of human intervention through felling operations can be observed when analysing the frequency indexes of species such as Penicillium ochro-chloron and Phomopsis meliloti. Thus, the frequency of Penicillium ochrochloron at amounts to 54.1 % at the section with clearcutting of the hornbeam trees, 48.3 % – at the section with shelterwood felling, and 47.7 % at the section with group-selection cutting of the understorey.

The similar tendency for frequency index holds true for Phomopsis meliloti. These species are entirely absent from the check section, which points to a negative response of rhizosphere to thinning treatment.

As a result of our observations, it was found that human-disturbed soils can promote the formation of associations of micromycelium fungi that are capable of surviving on the disrupted eco topes (soil compactness, excessive drying-up, soil acidification). The micromycelium fungi are antagonists to mycorrihza-forming fungi and are indicators of negative changes in the soil conditions.

In view of the fact that common oak plays an extremely important part in the formation of highly-productive, long-lived and valuable forests, combined with the fact that oak forests of seed origin are more resistant to adverse environmental effects, diseases, insect pests, it is necessary that appropriate conditions should be created for regeneration of oak forests by natural seeding [1].

Well-developed root system with prodigious taproot, which is a feature of oak trees originated from seed, enables this species to resist climatic extremes, particularly in the years with dry spring and summer [9]. Seed-originated oak forests have higher productive capacity at maturing and maturity ages. Natural regeneration of oak forests by natural seeding is much cheaper than artificial regeneration. However, this process is dependent on many external and internal factors. In particular, oak self-sowing in influenced by the site and climate conditions which may favour or hamper the development of reproductive organs and seed ripening. It is well-known that better soil-and-climatic conditions contribute to higher oak acorn yields. In particular, acorn yields in Belarus conditions may amount to about 530 kg/ha. Somewhat higher acorn yields are common to oak forests in the north-eastern parts of Ukraine (up to 1.5 ton/ha), the figures are still higher for the southern Forests-steppe (1.7-2.2 ton/ha), and the highest figures are to be found for oak forests in the western Forest-steppe, optimal conditions for common oak fruiting are formed in the oak forests with stocking index of 0.6-0.7 [8]. An important factors that essentially influences seed yields in oak forests, is the oak forest health and their ability to resist insect pests and pathogenic fungi attacks [13].

Acorn yields in old-growth stands were analysed at the Kornalovychi study area. Thus, over 82 thousand pieces of oak acorn per hectar was collected from the trial plots, 85 % of the acorn were damaged by insect pests and diseases. At the same time, acorn yield outside the study area was not large. Overall, the studies we conducted have revealed that the released acorns of common oak trees in the old-growth stands tend to be considerably damaged by insect pests and pathogenic fungi and do not meet permissible standards of conditioning. However, part of the common oak acorns may be considered sound and could be used for regeneration by seed of the old-growth, low-stocked, and weakend oak stands in the study area provided that appropriate standards are met and silvicultural treatments are timely conducted.

Further investigations into common oak fruiting at the sections of the permanent study area elucidated some specific features of this process. Thus, it was found that additional thinning treatment of the hornbeam-oak stands under conditions of moist hornbeam-oak forest type can enhance acorn yield of common oak trees (Table 2).

Table 2. Common oak acorn yields at the sections of the permanent study area over the years of observation, kg/ha

№	Reference years	Sections			
		1(check)	2	3	4
1	2006*	-	82.8±0.5	82.8±0.5	82.8±0.5
2	2007	37.4±1.1	569.1±11.7	518.0±18.3	414.5±15.2
3	2009	616.2±16.9	1565.3±43.1	786.7±21.6	705.3±19.8

Common oak acorn yields at the sections of the permanent study area over the years of observation, kg/ha.
* – On the average at the trial sections. The acorn yield at the check section was not determined.

As is seen from Table 2, the highest fruiting figures are found for common oak trees at the sections where clearcutting of the hornbeam trees in the understorey was made. Thus, a 2007-year acorn yield at this section was 1.1 times as large as that at section 3, 1.4 times higher than at section 4, and 15.2 times larger than at the check section (Section 1). Similar tendency was observed in 2009: the acorn yield there was almost 2 times larger than that at section 3, 2.2 times larger compared to section 4, and more than 2.5 times as large as that section 1.

A biometrical analysis of the oak advance regeneration at the sections of the study area and in the cutover area enabled to reveal a certain pattern in changes of the average height of the advance regeneration and the diametre of root collar.

Table 3. Biometrical characteristics of the common oak self-sown seedlings and advance growth at the section of the Kornalovychi permanent study area

Trial plots	Average height, cm			Average diameter, mm		
	Reference years			Reference years		
	2007	2008	2009	2007	2008	2009
1	2	3	4	5	6	7
Check	19.8±0.7	17.5±0.4	-	1.1±0.4	0.9±0.05	-
Section2	21.4±0.8	50.5±0.9	86.1±1.7	4.8±0.2	6.9±0.2	9.2±0.3
Section3	16.2±0.5	29.4±0.8	37.7±0.8	3.1±0.1	5.3±0.2	6.0±0.2
Section3	20.9±0.7	31.5±0.9	44.3±0.9	4.0±0.1	5.1±0.2	5.9±0.2

Biometrical characteristics of the common oak self-sown seedlings and advance growth at the section of the Kornalovychi permanent study area. Increased light intensity under the stand canopy favours the dynamic rise of the above values. At section 2 (clearcutting of hornbeam trees) and in the cutover area, there is a steady tendency for increasing values for the advance growth height and the diametre of the root collar.

Our studies make it possible to identify the factors that are determinant for regeneration of primary oak forests, these include:

- regular occurrence of oak fruiting;
- provision with sufficiently high level of light intensity to ensure survival of the oak self-sown seedlings;
- timely conducted silvicultural treatments which promote the emergence of considerable numbers of oak self-sown seedlings under the canopy of parent stands and stimulate their successful growth and development.

Conclusions:

1. The re-distribution of organic matter and chemical elements into the lower layers of the soil profile as well as changes in the soil reaction is strongly dependent on the intensity of anthropogenic impact on the hornbeam oakery (the thinning intensity of the hornbeam-participating understory). The most significant

decrease in humus content (by 28.2 %) in the upper horizon (0.0-10.0 cm) and gradual accumulation in the lower soil layers (11.0-40.0 cm) are observed at the section with clearcutting of the hornbeam understorey, which will favour the nutrition of root systems of old-growth trees and promote their fruiting, cutting and thinning treatments of the hornbeam layer by various methods of felling lead to the reduction of acid level in the upper horizons of the soil profile (up to a depth of 30cm), which provides more favourable conditions for acorns germination and development of the oak self-sown seedlings.

2. Cutting operations results in depletion of mycoflora in the soil. The section with clearcutting of the understorey showed disappearance of micromycelium symbionts and mycorrihza-forming fungi, which deteriorates the conditions for successful regeneration of oak stands by natural seeding. The species composition of fungi at the section with clearcutting become essentially depleted compared with the check section (14 and 27 species, respectively). It is characterized by the advent of species that are uncommon to the forest site involved (P.cuclopium, P.ochro-chloron, Sclerotium sp., Merothecium verrucaria et, Humicala sp., Aurobasidium pullulans, Phomopsis meliloti Grove), also symbionts are absent there.

3. Thinning treatment of the understorey in the hornbeam-oak old-growth stands stimulates fruiting of common oak. The most significant increase in the acorn yield in 2009 was observed at the sections with clearcutting of the understorey (by 2.5 times), somewhat less was the yield in the case of uniform shelterwood cutting(by1.3 times), and in the case of group-selection with the check section. Upon completion of cutting operations in 2006, over 82 thousand of oak acorns was recorded of which almost 85% was damaged by insect pests and pathogenic fungi.

4. Thinning treatment in the stands considerably promotes the emergence of self-sown seedlings. Thus in 2009, the greatest number of self-sown seedlings (17.2 thousand/ha) was recorded at the section with clearcutting of the hornbeam understorey, the figures were somewhat lower for uniform shelterwood cutting (10.8 thousand/ha), and for group-selection felling (6.3 thousand/ha) of hornbeam trees. The figures were the lowest for the check section (4.1 thousand/ha).

5. Increased light intensity under the canopy stimulates the growth rate and development of oak advance regeneration. The most steady increase in the average values for oak seedlings' height and the diametre of root collar was noted at the section with clearcutting of the understorey; the development of the oak advance regeneration was slightly slower at the sections with shelterwood and group-selection cutting of the hornbeam trees. At the check section, oak advance regeneration die already in the third year of life.

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УДК 630*622+630*116.28+630*111 ***Проф. Л.І. Копій, д-р с.-г. наук; асист. С.Л. Копій, канд. с.-г. наук; асист. В.В. Лентяков; доц. О.А. Чаплик – НЛТУ України***

Способи природного відтворення дубових лісостанів Західного лісостепу України

Проведено аналіз впливу лісогосподарських заходів на плодоношення, появу та динаміку відпаду підросту дуба звичайного, зміну мікологічної структури та перерозподіл поживних речовин у профілі грунту. Досліджено особливості приростів підросту дуба звичайного на секціях експерименту з різною інтенсивністю розрідження. Визначено вплив інтенсивності освітленості на зміну біометричних показників підросту дуба.

Ключові слова: природне поновлення, мікологічна структура, грунтовий профіль, дуб, екологія, лісівництво.

UDC 630*2:630*6:630*907.1 ***Assos. prof. Ya.V. Henyk; assos. prof. O.V. Henyk; assist. prof. M.P. Melnykovych – UNFU***

THREATS TO THE STABILITY AND SUSTAINABILITY OF FORESTS IN THE CARPATHIANS AND REASONS FOR LAW VIOLATIONS IN FOREST SECTOR IN THE CARPATHIAN REGION OF UKRAINE

Most significant threats for stability of forest ecosystems and significant factors leading to decrease of stability of Carpathian forests are determined on the basis of standard survey of experts. Major reasons of illegal cuts in the forests and law violations in forest economy in the Carpathian region of Ukraine are determined. Ecological, economic and social results of illegal wood cuts and law violations in Carpathians are highlighted.

Keywords: forest ecosystems, threats to stability of forests, factors for decrease of stability of forests, reasons for illegal wood cuts, reasons of law violations in the Carpathian forests.

Forest formations belong to the most common and most complex coenotic structure of plants. Today, one of the current problems faced by humans is protection of nature, its rational use and restoration of forests. Forest ecosystems play crucial role in preservation of biodiversity, establishment of favorable human environment, and ensuring the sustainable development of a country.

During the past decades the social importance of forests and approaches to economic and recreational use of forest ecosystems have changed significantly. Today, forest plantations are considered not only as source of wood for human needs, but also as ecosystems ensuring the spectrum of social, cultural and recreational services and supporting the environmental balance on the planet [1, 2, 3, 4, 5].

Because of the importance of forest ecosystems for ensuring the sustainability of living environment, detection of the threats for stability and sustainability of forest ecosystems as well as the reasons for illegal wood cuts in forestry and law violations in forest economy are very important topical issues. In the frames of ENPI-FLEG Program "Improvement of the system of legal application and management in forestry sector in the countries participating in European Neighborhood and Partnership Instrument and Russia" a survey on determination of most significant threats for stability and sustainability of forest ecosystems and reasons for law violations in the Carpathian forests has been held. The survey was held in three administrative districts of the Carpathian region in Ukraine (Kosivskyy District of Ivano-Frankivsk Region, Starosambirskyy District of

Lviv Region, and Khust District of Zakarpatya Region), which are characterized by high forest cover percent (square of forest lands makes 45 % of the whole area of the district) and relatively high volume of products, work and services of forest economy.

Methodology of research was based on 'face-to-face' questionnaire survey of experts at place of work (representatives of local authorities, business and forestry economy experts) and at place of residence (representatives of local communities). In general, there were 450 respondents (150 respondents in each of 3 districts) which allowed the correct and realistic evaluation of situation and determination of major threats for the state of forests and reasons for law violations in forest ecosystems or the Carpathian region. The results of sociological survey of population in the Carpathian region proved the crucial importance of forest and its resources for local communities.

To the question "For you personally, forest is …" community representatives responded that the forest is, first of all, an important nature object which must be protected (88.7 % respondents). At the same time forest is location for gathering mushrooms, berries and medicinal plants (86.7 %), and a place for recreation (78.0 %). Lower percentage of population in the Carpathian region considers the forest as a source of wood for economic needs (59.3 %) and residential heating (52.0 % respondents). Most significant threats for the state of forests in the Carpathian region of Ukraine, according to representatives of communities of mountainous districts are (Table 1):

- illegal wood cuts by local residents (80.7 % respondents);
- abuse in exploitation of forest resources by business structures (83.3 %);
- corruption in timber provision (83.3 %);
- lease of forests for temporary users (78.0 % respondents).

A significant part of population in forest regions in the country (over 70 %) considers that imperfect legislation, low ecological culture of the population and bad protection of forest by their users are major threats to the state of forests. According to the opinion of forestry specialists and scientists, most significant threats for the state of forests are:

- imperfect legislation (61.5 % respondents);
- illegal wood cuts by population (57.0 %);
- lease of forests to temporary users (55.0 %);
- low ecological culture of population (54.0 % respondents).

Residents of mountainous regions, forestry specialists and scientists mark illegal wood cuts by local population among to bethe most significant threats for the state of forest ecosystems.

According to the opinion of forestry specialists, most common violations in forests of the Carpathian region are illegal wood cuts made by local population for their own needs, especially for residential heating (34.0 % respondents), and also wood cuts made for getting profit from selling or processing of wood (23.7 % respondents).

The thoughts of residents of local communities and forestry specialists on the reasons of illegal wood cuts either coincide or are very close. So, the main reasons for illegal wood cuts by local population according to community residents are:

- low level of social protection of population (81.3 % respondents);
- functioning of illegal private sawmills (79.3 %);
- insufficient measures to combat smuggling and corruption (76.0 %);
- high level of unemployment (73.3 %);
- presence of shadow economy (70.7 % respondents).

Table 1. Most significant threats for the state of forests, % of respondents

Threats for the state of forests	Not a threat or rather is not a threat	Threat or significant threat
Visits of recreants to forests	81.3	15.3
Abuse in exploitation of forest resources by local authorities	48.7	48.7
Irrational activity of forestry enterprises	30.7	64.7
Imperfect legislation	26.7	70.0
Low ecological culture of population	24.7	72.7
Bad forest protection	24.0	73.3
Lease of forests to temporary users	18.0	78.0
Illegal wood cuts by local residents	16.0	80.7
Corruption in logging	13.3	83.3
Abuse in exploitation of forest resources by business structures	12.0	83.3

Forestry specialists consider the following reasons for illegal wood cuts by local population:

- high level of the unemployment (58.0 % respondents);
- low level of social protection of population (58.0 %);
- functioning of illegal private sawmills (48.0 %);
- low legal culture of population (44.0 % respondents).

Also, according to the opinion of forestry specialists and scientists, the following drawbacks in forestry management can be considered as reasons for illegal wood cuts in forests of mountainous regions:

- violation of regulations and laws in the field of lumbering;
- abatement of the systems of general and environmental management;
- lack of progress in implementation of the concept of sustainable forestry management.

The value of the harm caused by illegal wood cuts, according to the opinion of the majority of forestry specialists, is medium – 42.5 % respondents. 25.0 % respondents consider illegal wood cuts as insignificant volume of harm, and 20.5 % consider it as very significant. There is no exact answer of forestry specialists about effectiveness of fines and compensation amounts for illegal wood cuts. Thus, 22.0 % respondents consider the amounts of fines for illegal wood cuts as low, 34.5 % – as relevant to harm caused, and 37.0 % respondents – as too high. Most significant harm to forest ecosystems, according to opinions of forestry specialists and scientists, are caused by the following types of activities (Table 2): continuous wood cuts in large areas (38.7 % respondents); excessive chopping of forests by permanent cutting of best trees (43.3 %); illegal wood cuts (46.7 %); wood cuts near the rivers (48.0 %); damage to soils by tractors while timbering the trees (52.0 %); wood cuts on erosion-dangerous areas (58.0 % respondents).

Table 2. Evaluation of harm to forest ecosystems, % respondents

Factors	No harm	Insignificant harm	Significant harm
High level of manual work	45.3	32.0	16.0
Insufficient attention to protection of flora and fauna biodiversity	21.3	39.3	29.3
Lack of control over the sanitary condition of forests	13.3	48.7	32.7
Extensive wood cuts on big areas	11.3	40.0	38.7
Excessive chopping of forests by permanent cutting of best trees	10.0	37.3	43.3
Illegal wood cuts	10.0	35.3	46.7
Wood cuts near the rivers	10.7	31.3	48.0
Damage to soils by tractors while timbering the trees	14.7	28.0	52.0
Wood cuts on erosion-dangerous areas	8.7	2.3	58.0

Forestry specialists and scientists consider thefollowing reasons as most significant among the list of law violations in the forests of Carpathian region (Table 3):

- poverty of population (58.0 % respondents);
- high level of unemployment (68.0 %);
- insufficient funding of forestry enterprises (68.0 %);
- low wages of forestry enterprise employees (68.7 % respondents).

Table 3. Reasons of law violations in forestry sector, % respondents

Reasons of violations in forestry	No or partial impact	Significant or crucial impact
Lack of control from forest guard	68.0	24.7
Bureaucratic complications for citizens in legal use of forests	56.7	32.0
Difficulty in getting the permits for use of forests	56.0	30.0
Urgent need for wood	51.3	42.0
Absence of effective penalties	57.3	30.0
Imperfectness of forestry legislation	42.7	44.0
Presence of shadow economy	36.7	46.0
Desire for high revenues of business entities	40.7	46.0
Desire for additional income of population	37.7	53.3
Poverty of population	33.3	58.0
High level of unemployment	23.3	68.0
Insufficient funding of forestry enterprises	24.7	68.0
Low wages of forestry enterprise employees	22.0	68.7

Significant part of employees of forestry enterprises and scientists consider the desire to get additional income by local population (53.3 % of respondents), desire to get high revenues by business structures (46.0 %), presence of shadow economy (46.0 %) and imperfect forestry legislation (44.0 %) as main reasons of law violations in forests of the region. Law violations in forests and illegal logging caused by various factors lead to the following negative, closely intertwined environmental, economic and social results:

- decrease in stability and sustainability of forest ecosystems;
- attenuation of ecological functions of forests;
- changes in species composition, structure and productivity of forest plantations;
- decrease in the biodiversity;
- decrease in level of recreation attractiveness of forest stands;
- increase of expenses to ensure the recovery of forest ecosystems;
- conflicts in the field of forest use.

Conclusions. The research and analysis done allow for the following conclusions:

- forest ecosystems which are the basis for conservation of biological and landscape diversity play an extremely important role in ensuring the sustainable development of territories and stability of the environment;
- according to the opinions of specialists and representatives of communities of the Carpathian region, the highest threats for stability and sustainability of forest ecosystems are the following: illegal wood cuts by local population; abuses in exploitation of forest resources; corruption in logging, and imperfect legislation;
- the most significant harm to forest ecosystems is caused by the following types of activity: extensive wood cuts on big areas, excessive chopping of forests by permanent cutting of best trees, and illegal wood cuts;
- the main reasons for illegal wood cuts in the forest of the Carpathians are as follow: low level of social protection of population and high level of unemployment, operation of illegal sawmills, insufficient measures in combat the smuggling and corruption, and presence of shadow economy;

- the scientists and forestry specialists consider the following as most significant reasons of law violations in forests of the Carpathian region: poverty of the population and high level of unemployment, low wages of forestry enterprise employees, insufficient funding for forestry enterprises.

Despite the various developments in increasing the effectiveness of forestry and sustainable development of forest economy, the problem of reducing the number of law violations in forestry and volumes of illegal logging in the Carpathian region remain topical. Today the efforts should be directed on improvements in forestry legislation, maintaining the criteria of sustainable forestry use, and increasing the level of social standards of living, environmental education and legal culture of population.

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УДК 630*2:630*6:630*907.1
Доц. Я.В. Геник, канд. с.-г. наук; доц. О.В. Геник, канд. екон. наук; асист. М.П. Мельникович – НЛТУ України

Загрози стабільності та стійкості лісів Карпат і причини правопорушень у лісовому секторі Карпатського регіону України

Дослідження виконані в рамках Програми ENPI-FLEG „Удосконалення систем правозастосування й управління в лісовому секторі у країнах-учасницях Європейської політики добросусідства та Росії" та проведені в трьох пілотних районах Карпатського регіону України (Косівський район Івано-Франківської області, Старосамбірський район Львівської області та Хустський район Закарпатської області) дозволили встановити на основі стандартного опитування експертів „обличчям до обличчя" (450 респондентів – фахівці лісового господарства, науковці, лідери місцевих громад, представники органів місцевого самоврядування та бізнес-структур) найбільш вагомі загрози стабільності лісових екосистем та вагомі чинники, що призводять до зниження стійкості лісів Карпат. Найбільш вагомими загрозами для стану лісових екосистем експерти називають: самовільне вирубування лісів місцевими жителями, зловживання при експлуатації лісових ресурсів бізнес структурами, передача лісу в оренду тимчасовим лісокористувачам, корупційні схеми заготівлі деревини та недосконалу законодавчу базу. Проведені дослідження виявили основні причини самовільних рубань деревини у лісових масивах Карпат, першочерговими серед яких на думку мешканців громад та фахівців лісового господарства є: низький рівень соціального забезпечення населення та високий рівень безробіття, функціонування нелегальних приватних пилорам, наявність в економіці тіньового сектору та низька правова культура населення. За результатами досліджень встановлені основні причини правопорушень у лісовому господарстві та лісовій галузі Карпатського регіону України, першочерговими серед яких фахівці лісового господарства та науковці називають: високий рівень безробіття та бідність місцевого населення, недостатнє фінансування лісогосподарських підприємств, існування

тіньової економіки та недосконалість лісового законодавства. Правопорушення в лісових масивах та незаконні лісозаготівлі деревини, спричинені різними чинниками, призводять до низки негативних, тісно переплетених між собою екологічних, економічних та соціальних наслідків, основними серед яких є: зниження стабільності та стійкості лісових екосистем; зміна видового складу, структури та продуктивності лісових насаджень; значне збільшення витрат на забезпечення відновлення лісових екосистем; виникнення конфліктів у сфері лісокористування.

Ключові слова: лісові екосистеми, загрози стабільності лісів, чинники зниження стійкості лісів, причини самовільних рубань деревини, причини правопорушень в лісах Карпат.

UDC 631:331.4

***Post-graduate V.M. Stepanyshyn** –*
Lviv Polytechnic National University

EXPERT INVESTIGATIONS OF OCCUPATIONAL RISKS AT FORESTRY ENTERPRISES

The paper presents and analysis of the experience of qualified specialists – experts with the aim of danger identification and determination of occupational risks at workplaces by the rank correlation method. The results obtained will be used for the development of optimal planning methods for labour protection at forestry enterprises with the purpose of reducing occupational risks to a minimum.

Keywords: occupational risk, expert assesssment, rank correlation, concordance coefficient, Pearson's criterion, histogram.

Main theoretical material. The necessity of identification, estimation and development of methods for eliminating and reducing the occupational risks at each workplace are required by the standard OHSAS 18001.

There are statistical, analogue and expert calculation methods of occupational risks. Statistical and analogue methods are employed when corresponding statistics is provided, but it is not always available. That's why expert methods for identification and calculation of occupational risks based on the survey carried out among the specialists are applicable. It is important to use the information provided by the specialists-experts especially when for its selection, processing and analysis, special procedures and mathematical methods (called the methods of expert reviews) are employed. Rational use of information provided by the experts is possible under the conditions of converting it into a form convenient for further analysis directed towjrd preparation and taking decisions. The purpose of the rank correlation method is link evaluation among the objects of investigation. The ranks are used for arranging the significance of the objects. The target is to make a project using the available measures, arranged by the experts. The concordance coefficient ranging from zero (absence of agreement) to one (full agreement) is used for estimating agreements of the experts' opinions.

Given data. The objects X_1, $X_{2,}$ X_n are estimated. The specialists thoroughly acquainted with the objects under investigation arrange them according to the descending level of their influence on any index. Each j-object (factor) is given a rank of significance r_{ij} .The experts are provided with ranking maps of the objects under investigation.

On them they mark the ranks of significance of factors, which influence the index under investigation. On the base of these maps the reduced matrix $[r_{ij}]$ of dimension m x n is made. Natural series of numbers is presented in the matrix lines. The arithmetical average value is equal to:

$$1/n(1+2+...+n)=(n+1)/2, \quad (1)$$

hence the general average value is equal to: $$a = \frac{1}{2} \cdot m \cdot (n+1) \quad (2)$$

In the matrix [r_{ij}] small sized ranks can also exist. They occur when an expert can't prefer two or more objects (factors). For instance, if an expert can't arrange the objects with the ranks of 4 and 5, then he prescribes to these two objects the rank of (4+5)/2=4,5.

In the summary table the rankings of the experts are presented in lines and the ranks of objects of investigation are presented in columns (Table 1).

Table 1. A summary table of the expert reviews

Number of an expert	Objects of investigation			
	X_1	X_2	………	X_n
1	r_{11}	r_{12}	…….	r_{1n}
2	r_{21}	r_{22}	…….	r_{2n}
……	……	……	…….	……
m	r_{m1}	r_{m2}	…….	r_{mn}
Sum of ranks	$\sum_{i=1}^{m} r_{i1}$	$\sum_{i=1}^{m} r_{i2}$		$\sum_{i=1}^{m} r_{in}$

1. Calculation of the general average value of the table of ranks.

$$a = \frac{1}{2} \cdot m \cdot (n+1) \quad (3)$$

where m – number of the ranks; n – number of the objects of investigation.

2. Calculation of the sum of deviation squares.

At first we calculate the sum of deviation squares from the general average:

$$d_j^2 = \left(\sum_{i=1}^{m} a_{ij} - a \right)^2 \quad (4)$$

We calculate the sum of deviation squares:

$$S\left(d_j^2\right) = \sum_{j=1}^{n} \cdot \left(\sum_{i=1}^{m} a_{ij} - a \right)^2 \quad (5)$$

3. Calculation of the maximal sum of deviation squares.

It's proved that in case of full agreement of the experts' opinions the maximal sum of squares is equal to: $$S\left(d_j^2\right) = \frac{1}{12} \cdot m^2 \cdot \left(n^3 - n\right) \quad (6)$$

4. Calculation of the small-sized ranks index. With the availability of the small-sized ranks the maximal sum of squares is decreased to: $$m \sum_{i=1}^{e} T_i \quad (7)$$

where: $$T_i = \frac{1}{12} \cdot \sum_{u=1}^{g} \cdot \left(t_u^3 - t_u\right), \quad (8)$$

e – number of matrix lines containing connected ranks; g – number of types of the connected ranks in a line; t – quantity of the equal ranks in the i-line.

5. Calculation of the concordance coefficient. In case of the absence of the connected ranks the concordance coefficient is obtained as the ratio of the calculated sum $S = \left(d_j^2\right)$ to the maximal sum $S = \left(d_j^2\right)_{\max}$: $$W_p = \frac{\sum_{j=1}^{n} \cdot \left(\sum_{i=1}^{m} a_{ij} - a \right)}{\frac{1}{12} \cdot m^2 \cdot \left(n^3 - n\right)}, \quad (9)$$

in case of the availability of the connected ranks: $$W_p = \frac{\sum_{j=1}^{n} \cdot \left(\sum_{i=1}^{m} a_{ij} - a \right)}{\frac{1}{12} \cdot m^2 \cdot \left(n^3 - n\right) - m \cdot \sum_{i=1}^{e} T_i}, \quad (10)$$

6. Estimation of the concordance coefficient. It is determined that for the objects n > 7 the value $\left\lfloor m \cdot (n-1) \cdot W_p \right\rfloor$ has χ^2 – distribution (in case of n > 7 special Kendall's Tables are used):

$$\chi_p^2 = m \cdot (n-1) \cdot W_p, \quad (11)$$

7. Tacing a decision. In case that the calculated value χ^2 –distribution proves to be greater than that in the Table 3: $\chi_p^2 > \chi_t^2$ (f=n-1, g=0.05) (12)

for the number of degrees of freedom f and the given significance level g, the experts opinions are considered to be agreed.

In this case the diagram of ranks (histogram) is built, in which the objects of ranking are plotted discretely on the abscissa and the sum of ranks in the reverse order is plotted on the ordinate. The view of the fitting rank curve makes it possible to classify the objects (factors) into essential and unessential ones) [1, 2].

If the equation (12) is not satisfied, that is the experts opinions are not agreed, then we change the composition of the experts or the objects (factors) of investigation.

Getting table and graphic dependences. The experts are provided with the questionnaires in the form of Table 2, on which they mark the significance ranks of safety requirements violation, which can cause the accidents. The results of ranking the expert reviews at clearing works are presented in Table 3.

According to the results of the survey? the place of the factor in a rank row was determined, the summarized ranks were calculated and the ranking of problems was conducted. Afterwards the deviation from the average sum of the ranks, the concordance coefficient and Pearson's criterion were determined.

All these indices are calculated by the corresponding formulae given above.

Table 2. Influence of production factors on job safety and violation of labour protection requirements by workers which can cause the accidents

A QUESTIONNAIRE

№	Name of factors, violations	Rank of significance
1	Unavailable or incomplete instructing and training on labour protection.	
2	Operating defective equipment and unavailability of protective and holding devices.	
3	Not wearing working clothes and protective means.	
4	Not obeying the rules and violating instructions for labour protection.	
5	Low standards of work discipline (being not sober, doing extra work etc.).	
6	Absence of proper administrative control and supervision for obeying the rules of labour protection.	
7	Not following the instructions given by a work manager on labour protection.	
8	Non – qualitative occupational recruiting of workers, employing workers not by their qualification.	
9	Unprovided proper sanitary and hygienic conditions of work.	
10	Absence of stimulation and premiums for labour protection.	
11	Absence of mechanization and automatization of production processes.	
12	Absence of danger identification and risks estimation at workplaces.	

Table 3. A summary Table for ranking the experts opinions. – logging operations.

Experts	Factors											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
1	6	11	4	3	8	10	5	7	1	9	2	12
2	11	7	6	5	1	4	10	2	8	12	3	9
3	6	1	4	7	2	3	5	9	8	11	10	12
4	5	3	4	2	1	6	7	9	8	11	10	12
5	7	6	8	3	2	5	1	4	12	11	9	10
6	8	4	7	3	2	9	6	5	12	11	1	10
7	2	7	6	1	5	3	4	9	8	10	11	12
8	4	3	5	1	2	9	6	7	8	12	10	11
9	9	2	3	1	6	12	4	11	10	5	8	7
10	4	2	3	1	5	9	7	8	6	11	12	10
11	5	1	9	4	2	7	8	3	10	11	6	12
12	5	1	9	4	2	7	8	3	10	11	6	12
13	3	6	2	1	5	9	4	8	7	11	10	12
14	1	6	3	5	2	7	4	8	9	10	11	12
15	3	4	1	5	2	8	6	7	10	11	9	12
16	3	4	5	1	2	6	9	7	10	11	8	12
17	7	3	9	1	2	5	6	4	11	8	10	12
18	1	2	3	4	6	7	5	8	9	12	10	11
Sum of ranks Σa_{ij}	90	73	91	52	57	126	105	119	157	188	146	200
General average sum of ranks $a=\Sigma a_{ij/n=1404/12=117}$												
Ranking	4	3	5	1	2	8	6	7	10	11	9	12
Deviation from the average d_j	27	44	26	65	60	-9	12	-2	-40	-71	-29	-83
Deviation squares d_j^2	729	1936	676	4225	3600	81	144	4	1600	5041	841	6889

The concordance coefficient $W=12\cdot25766/18^2\cdot(12^3-12)=309192/555984=0{,}56$.

The estimation of the concordance coefficient $\chi_p^2=m\cdot(n-1)\cdot W=18\cdot(12-1)\cdot0{,}56=110{,}88$. In the case of the number of degrees of freedom f=n-1=12-1=11, the levels of significance g=5%, $\chi_t^2=19{,}57$. In the case of $\chi_p^2>\chi_t^2$ the experts opinions are considered to be agreed. In this case we construct a diagram of ranks (histogram) Fig. 1, in which we plot the objects of ranking on the abscissa, and the sum of ranks in reverse order is plotted on the ordinate.

Σa_{ij}

x_4 x_5 x_2 x_1 x_3 x_7 x_8 x_6 x_{11} x_9 x_{10} x_{12}

Fig. 1. A histogram of ranking the factors by the results of the expert reviews

In this case during the logging operations the determined Pearson's criterion is greater than that in the table taken at certain level of significance. That's why the experts' opinions are considered to be agreed. In the course of data processing of the results of the survey it was determined that the concordance coefficient lies in the range of the positive values, exactly greater than zero and equal to 0.56. It proves the agreement of the experts' opinions. The view of the fitting rank curve permits classifying factors into essential and unessential ones.

Conclusion. In the course of ranking and statistical processing of the survey results, in case of the agreement of the experts opinions, the greatest influence of the production factors on the job safety during logging operations and violation of labour protection requirements by the workers which can cause the injuries and accidents is observed under the followig conditions conditions:

- not obeying the rules and violating the instructions on labour protection;
- low standards of work discipline (being not sober, doing extra work etc.);
- operating defective equipment, unavailability of protective and holding devices;
- unavailable or incomplete instructing and training on labour protection;
- not wearing working clothes and personal protective means;
- not following the instructions given by a work manager on labour protection.

The conducted expert investigations and the results received coincide with the main characteristic reasons of the accidents considered during statistical processing of the occupational injuries at the forestry enterprises [3].

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УДК 631:331.4 ***Аспір. В.М. Степанишин – НУ «Львівська політехніка»***

Експертні дослідження професійного ризику на підприємствах лісового господарства

Проведено анкетування кваліфікованих спеціалістів-експертів та методом рангової кореляції визначено ранги важливості порушень вимог безпеки (фактори), що можуть привести до нещасних випадків. По результатах опитування було визначено місце, відведене фактору в рангувальному ряду, підраховані сумарні ранги і проведено рангування проблем, визначено відхилення від середньої суми рангів, квадрати відхилень, коефіцієнт конкордації і критерій Пірсона. Побудовано діаграму рангів (гістограму), визначивши найбільший вплив виробничих факторів (порушень) на безпеку праці на лісосічних роботах та ризики травмування працівників лісового господарства. Отримані результати стануть базовими для розроблення методики оптимального планування охорони праці з метою зменшення до мінімуму професійних ризиків.

Ключові слова: професійний ризик, експертні оцінки, рангова кореляція, коефіцієнт конкордації, критерій Пірсона, гістограма.

UDC 630*631:412: (417.2/4/7)

Prof. V.P. Ryabchuk;
post-graduate O.R. Kyrnychyshyn – UNFU

THE INFLUENCE OF SOIL CONDITIONS ON THE GROWTH AND DEVELOPMENT OF SPRING PRIMULA (*Primula veris* L.)

The main characteristics of soils on the trial plots that differ in their typological conditions have been studied. The values of the following soil indexes were determined: fertility index, acidity index, salinity index; also the distribution and development of the population of the species involved was revealed. The soil nutrient content necessary for the primula species growth was investigated.

Keywords: *Primula veris* L., site conditions, flowering productivity, degree of availabity, acidity, salinity, alkalihydrolyzed nitrogen, soil fertility, humus.

Introduction. The soil is a complex subekosystem which is constantly changing and developing according to the laws of soil formation. This is the main of plant life-support factors, the environment, in which numerous exchanging processes go on between the soil and plants. An important prerequisite to the formation of stable coenopopulations as well as their ability for reproduction is a favorable combination of physical-and-chemical, biochemical, thermal properties of the soil, the soil depth and groundwater level also being of significance. The depth of humus and illuvial horizons (A – and B horizons), the characteristics of parent material, the presence of leached or calcareous horizons, their granulometric composition determine the totality of physical, chemical and biological indicators of soil fertility as well as the environmental conditions that are to meet the requirements of particular plants [1, 2, 8, 9, 13].

Primula veris L. is one of herbaceous plants that have found wide practical use including planting greenery in towns and cities. In the process of transplanting a plant into other soil environment, great amount of nutrients is taken together with the roots, which will result in agrochemical changes in the soil horizon and floristic composition of the phytocoenosis as a whole [6, 7, 11, 13]. The removal of nutrients together with plant organisms is not only an indicator of consumption of growth life-support factors, but also an indicatjh of a significant growth and development of the plants that have remained on the exploited site. Therefore, the supply of nutrients in the soil, under conditions of non-deficient balanced, must meet the requirements of the plants that are associated with a particular site type and the soil-and-climatic growing conditions [4, 5, 14].The peculiarities of the soil may have a significant impact on the development of phytocoenosis and its populations of the species under study. That is why the necessity of studying the soil conditions for the members of the plant world is a primary task for a wide circle of researchers.

The objective of the study. A series of investigations are focused on the study of the effect of soil factors on the growth and development of *Primula veris* L. The present work is aimed: (1) at revealing agro-ecological peculiarities of the soil under different typological conditions, (2) to investigate the influence of physical-and-chemical properties of the soil on the pattern of the species development, (3) to identify the degree of plant nutrients availability and clarify its effect on flowering productivity of *Primula veris* L.

Materials and methods. In order to study the main agroecological characteristics of the soil, we took soil samples from 12 plots that vary in their forest typological conditions. The study was based on the commonly accepted methods for identification of the main soil characteristics [3, 6, 12, 17].

Results. Soil acidity has a profound effect on the growth of forest vegetation and its vital activity processes: seed germination and shoot growth, formation and development of generative and vegetative organs. The degree of soil salinity is an indicator that determines the possibilities of formation and functioning of a certain plant populations under certain soil conditions [10, 14].

For the most species of grass cover, the following soil reaction is considered favorable: neutral (pH> 6) or near-to-neutral (pH = 5.6-6.0) reaction of the soil solution. However, there are plants that are able to grow and develop only under conditions of weakly acid soil reaction (pH = 5.1 to 5.5) or medium acid soil reaction (pH = 4.6 to 5.0). Quite a few members of the plant world make a successful growth on highly – acidity soils (pH 4.1 to 4.5) and also on extremely high acidity soils (pH <4.0) [4, 12]. The acidity and pH of salinity limits under different site type conditions for the *Primula veris* L. growth in the grass cover are given in Table 1.

The soil on the study sites is characterized by hydrolytic acidity values ranging from 0.40 to 3.63 mg-equiv.; these are conditions of a fresh fertile site type. The flowering productivity of *Primula veris* L. under such conditions makes up 16.6-41.2%. On identifying the degree of salinity, it should be noted that the limit for pH salinity extract makes up 5.1 to 7.0 mg-equiv. On less acid, saline soils, the share of flower-bearing stems which are able of setting ovary makes up 41.2%. The plots that have the highest value of hydrolytic acidity (3.63 mg-equiv.), with the value of pH salinity being equal to 6.9 mg-equiv. are characterized by a relatively low productivity index (16.6 %). It should be pointed out that pH values for fresh and wet fairly infertile site types vary between 5.4 and 6.7, while the index value for hydrolytic acidity makes up 1.13 – 3.11 mg-equiv. Fresh and wet fairly fertile site types are characterized by soil indexes ranging as follows: hydrolytic acidity – 2.63-3.59 mg-equiv.; salinity level – 5.0-5.5 mg-equiv. Under conditions of fresh and wet fertile site types ($D_{2\text{-}3}$), pH value is equal to 5.8-7.0, hydrolytic acidity values ranging from 0.4 to 3.63 mg-equiv. At the lowest hydrolytic acidity value (0.40 mg-equiv.), the highest productivity index of flowering reaches 41.2%, while at the highest hydrolytic acidity value (3.41 mg-equiv.) the number of flowering organs on the inventory plot is considerably smaller: 16.2%.

Table 1. The influence of hydrolytic acidity and pH salinity of soils on the number of *Primula veris* L. plants for various edatopes

Trofotope	Higrotope	Sample plot	Soil indexes		Plant indexes		
			hydrolytic acidity, mg-equiv. per 100g of soil	ph salinity	the number of plants, pcs/m^2		percentage of plants with flowers, %
					in total	with flowers	
B	2	2	3.11	5.4	179	44	24.6
		6	1.56	6.1	108	21	19.4
	3	13	1.13	6.2	28	7	25.0
		17	1.26	6.7	71	28	39.4
C	2	5	3.41	5.5	112	19	16.9
		15	3.59	5.0	164	23	14.0
	3	1	2.46	5.1	150	48	32.0
		3	2.63	5.2	57	21	36.8
D	2	12	3.63	6.3	42	7	16.6
		21	0.40	7.0	165	68	41.2
	3	4	2.03	5.8	73	21	28.6
		16	1.64	6.9	138	20	14.5

The soil fertility level and humus content are closely related to the presence of nutrients in the form available for plant uptake: nitrogen oxides, phosphorus, potassium, calcium and others. The soil commonly contains large supplies of nutrients in the form not available for plant uptake, but these can be transformed into soluble form due to the plant-soil interaction. Phosphates create a most important buffer system in plants, nitrogen compounds are the basic components of amino acids from which proteins are synthesized [9, 10, 14, 16]. The influence of soil nutrients on the flowering productivity is shown in Table 2.

The soil, as is evidenced by the data in Table 2, is characterized by high humus content. Whatever the site type is, these values fluctuate in the range from 5.20 to 9.89%. With these values, the flowering productivity of the *Primula veris* L. plants makes up 14.0-41.2%. In the soils having the lowest content of alkalihydrolyzed nitrogen (154.0 mg/kg) the flowering productivity makes up 39.4%, while at the highest content of nitrogen compounds (308.0 mg/kg) the share of flowering plants is 25.0%. The lowest content of K_2O (88 mg/kg) is found under conditions of a wet fairly infertile site type, while its content is the highest (481 mg/kg) under conditions of a wet fairly fertile site type. The flowering productivity makes up 39.4 and 32.0% for the lowest potassium content and for the highest potassium content respectively. We will point out that the lowest phosphorus compounds content in the soil (37 mg/kg – wet fairly fertile site type) corresponds to a 36.0% flowering productivity *Primula veris* L. whereas the highest content (141.0 mg/kg – wet fairly site type) corresponds to the share of flowering plants of 14.5 %.

Table 2. The influence of soil nutrient elements on the *Primula veris* L. flowering productivity

Tro-fotope	Higro-tope	Sample plot	Soil indexes				Share of flowering plants, %
			P_2O_5 mg/kg	K_2O mg/kg	Alkalihydrolyzed nitrogen, mg/kg	Humus content, %	
B	2	2	94	119	198.0	7.21	24.6
		6	59	86	169.0	6.90	19.4
	3	13	82	95	308.0	9.89	25.0
		17	73	88	154.0	4.20	39.4
C	2	5	97	127	226.9	6.12	16.9
		15	46	189	200.6	5.20	14.0
	3	1	37	418	268.8	6.42	32.0
		3	50	186	205.2	4.76	36.8
D	2	12	41	148	198.8	4.82	16.6
		21	134	367	291.2	8.94	41.2
	3	4	105	122	206.9	7.59	28.6
		16	141	139	199.5	4.43	14.5

Conclusions. The results of the agrochemical analysis of the soil lead to the following conclusions: the species under study tends to grow and establish populations in the neutral soil environment with pH values ranging from 5.0 to 7.0; the limit values hydrolytic acidity make up 0.40-3.63 mg-equiv.; the degree of soil fertility on the sample plots is characterized by a high value (the humus content make up 5.20-9.89 %). Thus, the most suitable conditions for the growth and development of the *Primula veris* L. populations are wet fairly infertile and wet fairly fertile site type. The level of available soil nutrients, the soil fertility and acidity indexes have an impact on the formation of a certain share of flower-bearing stems.

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УДК 630*631:412.: (417.2/4/7)
Проф. В.П. Рябчук, д-р с.-г. наук;
аспір. О.Р. Кирничишин – НЛТУ України

Вплив ґрунтових умов на ріст та розвиток первоцвіту весняного (*Primula veris* L.)

Вивчено основні особливості ґрунту на пробних площах, відмінних між собою за типологічними умовами. Виявлено показники родючості, кислотності, ступеня засоленості ґрунтів та їх вплив на поширення та розвиток популяцій досліджуваного виду. Досліджено вміст елементів ґрунтового живлення для особин первоцвіту весняного.
Ключові слова: первоцвіт весняний, лісорослинні умови, продуктивність цвітіння, ступінь забезпечення, кислотність, засоленість, лужногідролізований азот, родючість ґрунту, гумус.

UDC 630.43
Environmental eng. Iryna Skulska Kolos – Environment and Territorial Planning Department, University of Aveiro, Aveiro city, Portugal; senior teacher Oksana Mychayliv – UNFU, Lviv, Ukraine

IBERIAN PENINSULA'S FIRE ORIGIN INVESTIGATION

Analyzed in this work are causes of forest fires in the Iberian Peninsula's Mediterranean forests; also the influence of weather conditions and socio-economic factors on the fire frequency and intensity is considered.
Keywords: forest fires, Mediterranean forests; climatic factors, socio-economic factors.

Introduction. Each year, thousands of fires sweep over the grasslands, woods and forests destroying millions of vegetation acres in the five continents of our planet. The country region of the Mediterranean basin makes a significant contribution to the statistics of this kind. The forest fire frequency and intensity in the Iberian Peninsula during the last decade have assumed a menacing character adversely affecting the environment and having dramatic impacts on economic and social life of the region.

The direct material losses, although great they might be, are relatively easy to assess after the fire occurrence, while the other impacts may persist for many years having far-reaching implications.

Purpose. An analysis of the main causes of forest fires based on the statistics study of this phenomenon, special attention being given to the fire peculiarities caused by anthropogenic factors as the leading cause of forest fires; also the present work seeks to trace the relationship between the fires occurrence and the state and type of the forest management in west of the Mediterranean region.

Material and methods. The analysis of forest fires in the Iberian Peninsula and their causes was made on the basis of official statistics of the European Forest Fire Information System [EFFIS] whose main mission is to regularly provide the European Commission and the European Parliament with reliable information about forest fire occurrence in Europe. Analyzed here are the annual reports of Forest Resources General Direction [FRGD], the organ responsible for collecting annual data on the number of fires, their causes as well as the size of fire-affected areas.

The paper also analyzes satellite-taken pictures by NASA and the data available on the internet and other media. We have attempted to investigate: (1) the "cause-effects" relationships between the number of forest fires and the condition of forest management (namely, a sharp deterioration due to the increasing amount of abandoned and neglected forest areas; (2) depreciation of fire-affected forest resources; (3) the reasons of careless use of sources of ignition.

Forest fires in the Mediterranean region. Each year, forest fires destroy hundreds of thousand acres of land ecosystems in the Mediterranean region. The Iberian Peninsula, the south-west part of Europe, is effected the most by this phenomenon/ It is here that the largest portion of the Mediterranean forest is concentrated. The Iberian Peninsula forests are distributed between the territories of the countries such as Spain and Portugal (over 95 %), Gibraltar and Andorra [28]. The works related to risk assessment of forest fires (probability of a fire occurrence) caused by the climatic factors of the region show that the origin and spread of a fire, in most cases, are controlled by highly qualified professionals. However, there are situations when the fire may evolve into a disaster increasing its destructive potency under the influence of anthropogenic factors. Fig. 1 shows the dynamics of forest fires in the Mediterranean countries during the last 20 years.

The analysis of the last few decades shows that the forest fire situation has significantly aggravated, especially in the Iberian Peninsula countries (Portugal and Spain) where the total number of forest fires is larger. According to the statistical data of the last 10 years [9], the total area affected by forest fires in Portugal amounts to 17.0 %, in Spain – 2.4 %, while in France it reaches 0.32 %, and 2,8 % in Italy [9]. This tendency may be associated primarily with the type of climate in the study region; forest fire are more common in region with pronounced dry seasons when the weather conditions lead to desiccation of the vegetation, which may be the case, for example, on steep slopes in the mountainous country. When analyzing the fire phenomena occurrence, it might be reasonable to suppose, from a logical point of view, that in the years after large conflagrations the risk of fire ignition is reduced due to the obvious reduction in fuel accumulations. However, as is evident from Fig. 1, the number of fire ignitions in the year following high-severity fires in Portugal and Spain do not decrease; on the contrary, some years can see an increase in the number of fires.

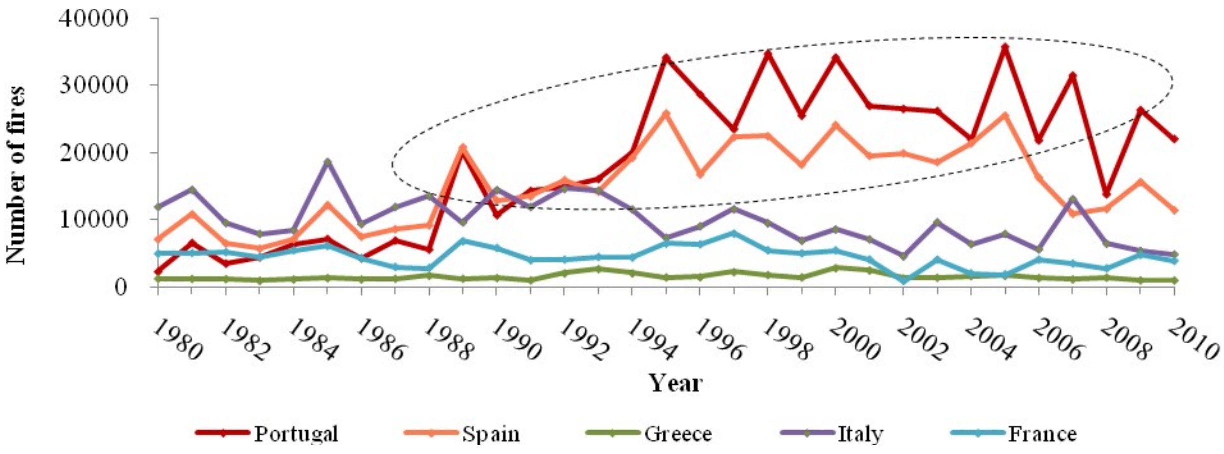

Fig. 1. Number of fires from 1980 to 2011 in Mediterranean countries [9]

The causes of the forest fires are different in nature. The results from the existent studies show that over 90-95 % of these fires is caused by human activity [3, 5, 6, 7, 9, 12], the basis for this being a decline in living standards of the population, which is often manifested in human's negligence and careless treatment of the environment.

The investigation process of forest fires is based on the analysis of concrete and convincing evidence. It also involves modeling a fire behavior and other factors that could cause the fire or contribute to its speed. Also, it is essential to establish relationship between the fuel material and ignition source. On compiling a list of fire-initiating factors of natural and / or anthropogenic character, the information is analyzed and classified according to the categories of fires causes [6].

The results of this analysis are sent to the Prosecutor General of the district and, in case of revealing intentionally planned fires, the case is passed to Judicial Police, criminal police authority which deals with such kinds of case [11]. During the last decade, the Iberian Peninsula forest areas have suffered significant losses in terms of the size of areas burned and unique and rare species destroyed [10]. In Spain, as in Portugal, there was a drastic increase in areas affected by fires as compared with other Mediterranean countries. In the 2000-2011 periods, the fires devastated over 1.5 million hectares of forest land. In Portugal representing about 17.0 % of the country's total area and 45 % of the forested area; over 1.2 million acres of forest land was destroyed in Spain (2.4 % and 10.0 %, respectively [8].

The FRED is responsible for the formation, maintenance and functioning of a data bank on forest fires; the data bank covers the EU's territory [7] through the Forest Fire Management Information System (FFMIS), it also contains cartographic images of fire-affected areas [9].

The Regulation No. 804/94 enacted by the European Commission is a binding document to all EU's member countries with areas of high or moderate level of fire danger, also serving as the basis for large-scale international cooperation.

The peculiarities of fire spread in the Iberian Peninsula. In analyzing forest fire development, it is, first of all, necessary to take into account large-sized fires that cause great damages to the vegetation cover and the soil under the influence of high temperatures. The fires of this sort should be given special attention due to the alarmingly higher frequency of their occurrence (Fig. 2). This is largely caused by numerous environmental factors as well as by socio-economic ones.

A detailed analysis of Fig. 2 shows that in Portugal the largest number of fires occurred between the years 2003 and 2006 destroying a total of about 900 thousand hectares, which represents about 10 % of the total area of the country. It should be noted that the fires intensity during the reference period was really high, which can by seen through the analysis of the satellite images provided by NASA/GSF/08/2005 [15] (Fig. 3). It is also important to note that a large number of fires do not necessarily result in sizable burned areas.

Thus in Spain, in 1994, 19 thousand fires burned about 440 440 thousand hectares of forest land (Fig. 2). But there are periods when the size of burned area exceeds 200 thousand hectares a year or even 400 thousand hectares a year (1990 – 1991 and 1994-2005). According to the FRGD [7], the economic annual losses caused by forest fires in Portugal and Spain estimate at about a million Euros.

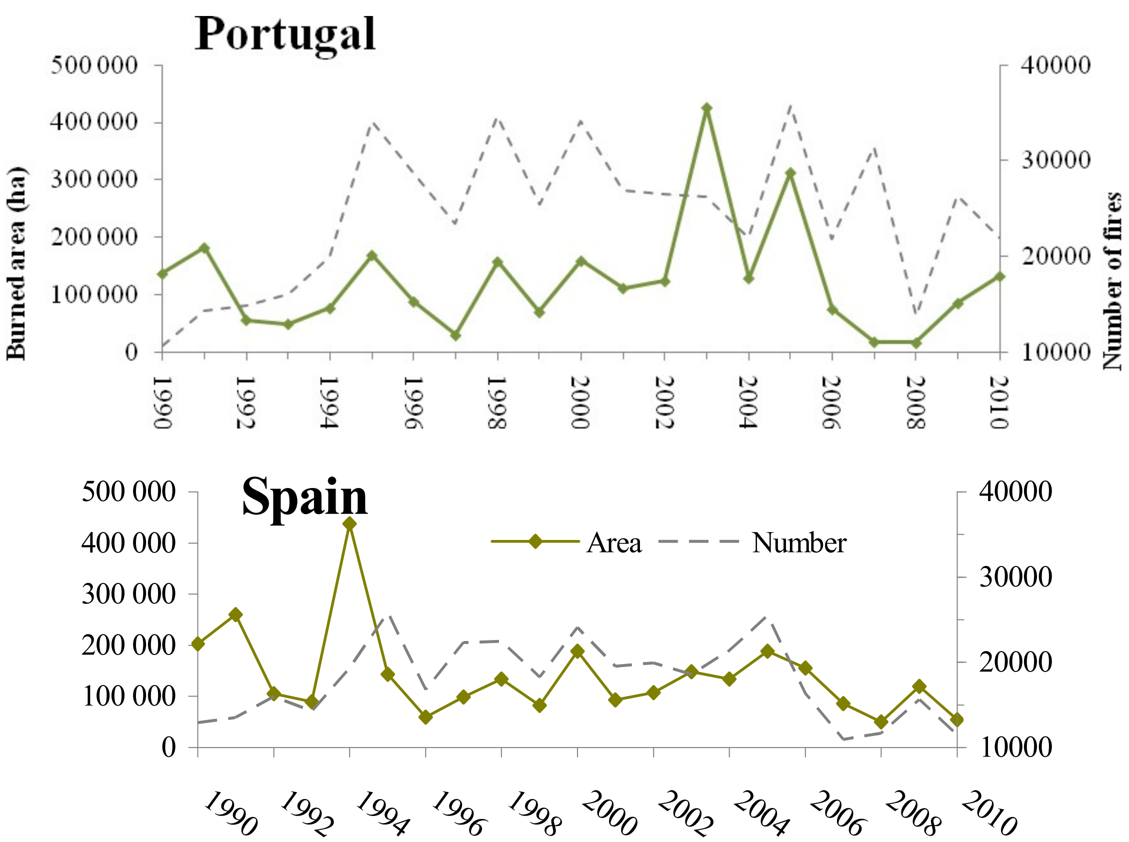

Fig. 2. Areas burned by fires and conflagrations

The leading causes of fires. In view of the current tendency towards an increase in the number of forest fires as well as the extent of damages caused by their occurrence, it is of great importance that this phenomenon causes should be thoroughly analyzed. It is obvious that the majority of these fires in one way or another is caused by anthropogenic factors. The causes of forest fires in Portugal and Spain are quantitavely presented in Fig. 4.

Fig. 3. Satellite images of forest fires occurred during a 10-day period in the Iberian Peninsula, July 2005 [15]

According to the official statistics, about 70-90 % of fires are related directly or indirectly to human activities. A recent statistical compilation of fire reports indicates that the leading cause has been arson (pyromania, fighting means, protest against the existent legislation) [21]. Thus, in 2010, the National Guard Portugal proceeded with criminal investigations of 13,500 forest fires (61 % of the total of forest fires recorded in 2010). Intentional fires correspond to 48 % of the determined causes, accidental or actionable (negligence) fires amounted to 50 % of the fire ignition (Fig. 4).

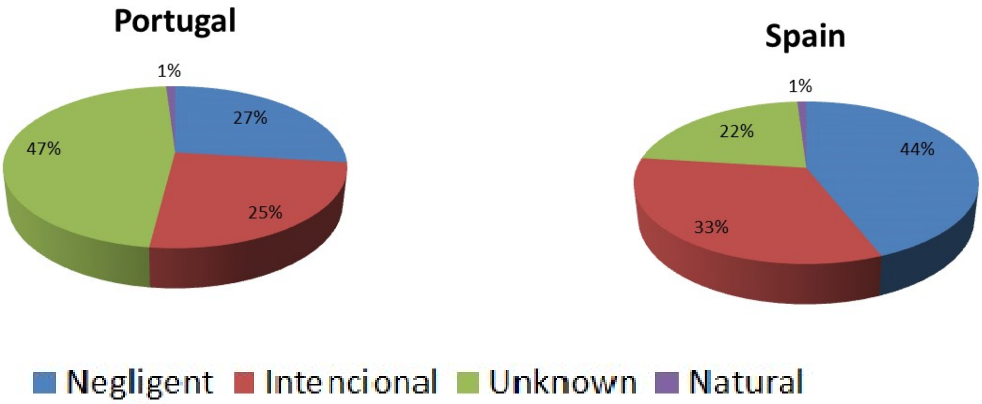

Fig. 4. The fires causes in Portugal and Spain in 2010 [9]

Pasture renewal and land clearance for agriculture represented 68% of the accidental and actionable fires [9]. The motives that make the people burn forests are several by their nature. First, the motives are socio-economic or political [24], such as personal insults, farmers' protest against creation of new forest land; public interest in obtaining subsidies annually assigned by EU to the reforestation of areas burned: hunters' dissatisfaction about the decrease in hunting area; dissatisfaction of the forest land owners with the intervention of central, regional or local authorities; passage of decrees and regulations that contradict the economic interests of the forest land owners, etc.

The percentage of fires provoked by high air temperatures is relatively small in Portugal and Spain with the average of 2-4% during the last 12 years [12, 21].

Analyzing the causes of large-sized fires whose area reaches over 500 hectares, it was found that the percentage of fires originated from natural causes has increased up to 8-10%, while the percentage of arson fires has decreased to 30-40 % [25].

Although the difference is not that considerable it is meaningful and shows the importance of climatic factors influence on the fire occurrence. Curiously, the fire causes distribution is different is we compare the Mediterranean land ecosystems with land ecosystems in other parts of our planet. Thus in California, the energy of the solar radiation causes up to 40 % of the annual fires [25].

Natural factors affecting the ignition and spread of fires. In most cases, a fire results from the interaction of socio-economic and environmental factors [8, 10, 11]. The identification of such interaction not only explains the leading forest fire causes but also helps promote fire prevention and reduce the number of these fires. The main factor that explains rapid forest fire spread in the Iberian Peninsula is the hydrostress of vegetation during summer months. High temperatures and small amounts of precipitation during a dry season of the year cause the development in vegetal organisms of a number of adaptation mechanisms that enable the plants to survive during the period of severe drought. These adaptive changes can develop only in those parts of plants that are usually fire-resistant because of the higher moisture content during relatively humid weather; those parts of plants are leaves and twigs. With the advent of a pronounced dry season, the plants begin to rapidly lose moisture through leaves and small twigs in order to ensure survival of the whole plant. These cured leaves and twigs become extremely flammable and may contribute significantly to fire intensity and rate of spread.

Especially sensitive to the increased temperature are forest floor and understory vegetation whose moisture content influences directly the rate of forest fire spread. The Iberian Peninsula forests are dominated by low density forest cover (open forests), a lot of low shrubs, grass and herbs [13] when in cured condition make the ignition probability much higher than in the closed forest. The Iberian Peninsula climate in the South is influenced by dry and warm air masses coming from the Mediterranean region and the North of Africa, which results in mild winters and really warm summers. Moist weather dominates in the North and is determined by the influence of the Atlantic Ocean from where moist and cold winds blow [28]. The development of fires in the Peninsula mountainous regions is dependent on the slope steepness and prevailing wind direction. It was found that for each 10 % inclination increase, the rate of fire spread is doubled [23]. The climatic conditions in the Iberian Peninsula are characterized by great diversity and strong contrasts comparing with the rest of the South Europe territory. This is attributable to the proximity to Africa: hot winds from the Sahara penetrate the Peninsula making the climate and landscapes of Andalusia, Murcia, Valencia, Baleares and even Alentejo and Algarve much similar to those of the North of Africa.

An analysis of socio-economic impacts. According to the 2010-2011 inventory data, 80-90 % of Spain's and Portugal's forests are private property. Over a long period of time, the rural population traditionally used the forest as a source of making their living. In the late 19th century – the early 20th century, a considerable amount of farm lands was converted into large plantations of pine. In the midnineteenth century eucalyptus species was introduced in the Iberian Peninsula. Over a 60-year period, the area of eucalyptus plantations increased from 100 thousand hectares to 300 thousand hectares [27]. Such a change in the land use has led to an increase in areas of fuel heavy accumulations and also to landscapes conducive to fire spread. Vast forested areas have been abandoned in recent years because they are not economically attractive any longer; also a decrease in rural population contributed to the increasing amount of areas totally abandoned or mismanaged. At present, the main functions of forestry in the Iberian Peninsula are limited, actually, to the production of those forest species whose wood is of high quality and is in demand on the market, these are oak, chestnut. Also cultivated intensively are fast-growing species such as eucalyptus and pine. Most of these plantations are pure stands prone to the development and spread of a forest fire. Another interesting point to consider is the evolution of the rural area panorama and increasing landscape homogenization. A considerable body of land has become totally abandoned without any indication farming activity. As a results, the tendency has been toward single-purpose use of the land, that is cultivations of exotic, fast-growing, introduced species (eucalyptus, acacia) [4, 14]. Normally, these areas have the potential of accumulating large amounts of flammable fuel by increasing the thickness of surface litter during the growing season [7, 16, 17, 19, 20, 22]. Therefore, the fires that occur in such areas have the power of rapid and long-distance spread with probability of turning into a disaster [2]. The current legislation in both countries is trying to solve this problem by making the owners of the plantations control and reduce the accumulation of flammable material. To encourage the people to implement silvicultural preventive activities against fires, the governments have passed a number of laws that offer economic support in the form of subsidies. However, the degradation processes in the forest management and the lack of interest to develop the forestry due to low profitability are becoming increasingly aggravated. The acts and regulations recently enacted with the aim of rendering financial aid to the local population are, unfortunately, insufficient to stop the degradation processes in the current forestry.

Degradation of suitable areas for pasture. Another important problem is misuse of fires in the areas designed for pasture [3, 10, 13]. The persistent reduction in the rural population and increasing areas of abandoned pasture is a factor that makes it almost impossible to control the pasture fires. By virtue of the fact that these pastures are often located in the immediate neighbourhood of the forests, the fire can easily spread to the forested land [25]. The problems of uncontrolled burning are not adequately explained and discussed with the local population due to insufficient public education on this point.

Areas of specific form of protection. The establishment of protected areas (national parks, reserves, etc.) always involves certain restrictions aimed at protection and preservation of natural resources. Such limitations on the use of protected areas may have a direct impact on the life of local inhabitants and, under certain circumstances, this can provoke a conflict. In such situations, the fire acts like the local people's protest against the current law that encroaches on their interests.

Reforestation of the burned areas. The regeneration methods of fire-affected areas vary widely. The general tendency of forest management in Portugal and Spain consists in the principles of integrated forest species associations [3, 13, 26].

At present, the European Union is launching a vigorous campaign whose main idea is the protection and conservation of biodiversity of natural ecosystems. Unfortunately, there is no efficient document adopted which could encourage and promote the creation of mixed stand-based forestry.

Recreational use of forests. A certain percentage of annual forest fires results from careless recreational use of forest areas especially by tourists and hunters [6, 8, 9, 10, 12]. The latter can use fire to remove animals from the forest during hunting. In order to straighten out the existing security standards for recreational use of the forest, a number of regulations have been adopted lately one of which aim is to control and limit the number of visitors particularly during hot summer periods when the forest fire danger is especially high [3, 7]. In the 1960s and 1970s, a large number of recreation areas and vacation homes were established within the forested areas. However, the access to those areas is currently denied because of higher danger of forest fires [3]. The forest fire problems are becoming increasingly important and, in our opinion, they must be included in the scholar educational curriculum. The issues such as forest fires, fire causes, fire impacts on the environment and human beings must be included in the general education programme. “Criminal Negligence” in the use of fire in the forest area must be included in the Criminal Code as a law supplement.

Conclusions. The total area affected by fire in the Iberian Union between the years of 2000 and 2010 amounts to over 2.5 million hectares. Thus, the countries of the Iberian Union at the beginning of the current decade ranked first among other European countries in terms of the number of fire events and the size of area burned.

In recent years, considerable attention has been focussed on the study of the forest fire phenomenon by way of constructing models of the fire causes, patterns of fire development and spread. Today, an extensive literature has evolved related to investigations of fire effects on forest ecosystems. Throughout history, man has tried to use fire as a simple and available instrument that can alter the type of land cover over the large area in no time. Occasionally, arson may be used as a mean of taking revenge on the neighbours, the local authorities, etc.

However, the leading causes of forest fires that have occurred in the Iberian Peninsula in the recent decade, can be attributed in most cases, to the negligence of safety rules in any type of fire event, especially in the case of fire for recreational or farming purposes. The danger of forest fires is growing from year to year due to the outflow of population from the rural areas and consequent decline in forestry, which results in degradation of forests with extremely large accumulations of flammable fuel. The incapability of current forestry policy and legislation to ensure a harmonious interaction between wood market needs and the necessity of biodiversity preservation contributes towards further aggravation of the problems.

The fact that the forest lands are fragmented and belong to different owners complicates the introduction of the principle of sustainable forest management in the Iberian Peninsula. The forest sector in the Iberian Peninsula is beyond the EU’s competence, unlike the farming sector which is an object to the Common Agricultural Policy, and the determination of forest policy is the responsibility of Member States [21] where the forest management is executed through Regional Forest Planning [3, 7].

In order to solve the existing problems, changes in the current legislation are called for. In view of possible further aggravation on the environmental situation due to forest fire-damaged land areas, it is necessary that strategic measures should be worked out to prevent forest fire hazards.

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УДК 630.43 *Інж.-еколог І. Скульська-Колос – Департамент Навколишнього середовища і територіального планування, Університет Авейру, Авейру, Португалія; ст. викл. О. Михайлів – НЛТУ України, Львів*

Причини поширення пожеж на піренейському півострові

Проаналізовано причини виникнення лісових пожеж, вплив погодних умов і соціально-економічних факторів а частоту та інтенсивність лісових пожеж. В останні 10 років частота та інтенсивність пожеж на Іберійському півострові набула загрозливого характеру, загалом за цей період площа лісів охоплених пожежами сягнула 2,5 млн. га. Ці країни займають перше місце серед Європейських країн за розмірами пошкоджених територій. В останні роки велику увагу приділяють вивченню причин, які посприяли такій ситуації. Серед соціально-економічних чинників основною причиною є занепад сільського і лісового господарства, деградація земель, що веде за собою накопичення горючих матеріалів. А також неспроможність законодавства втримати врегульований взаємозв'язок інтенсивного ведення господарства і біологічною різноманітністю. Проаналізовано вплив на високий рівень пожежної небезпеки рекреаційне використання земель півострова, великий наплив туристів і недбалість відпочиваючих. На посушливий клімат Іберійського півострова великий вплив має близьке розташування до Північної Африки і дуже нагадує клімат цього континенту. Як наслідок ліси є розрідженими, відкритими, низькоповнотними і низько зімкнутими, які добре прогріваються. Сама рослинність, що проростає в посушливих умовах і віддає зайву вологу стає сухішою і легше загорається.

Ключові слова: лісові пожежі, середземноморські ліси, кліматичні чинники, соціально-економічні чинники.

UDC 630*231 : 633.877.12 *Prof., Dr. habil. Erwin Hussendörfer – University of Applied Sciences, Freising, Germany; assoc. prof., Dr. V. Lavnyy – UNFU, Lviv*

SILVER FIR (*Abies alba Mill.*) IN BAVARIA AND THE UKRAINIAN CARPATHIANS

In the article the ecological and silvicultural peculiarities of Abies alba Mill. are discussed. The current distribution of Silver Fir forests in Bavaria (Germany) and in the Ukrainian Carpathians is described. There are the reasons between actual and natural amount of Silver Fir stands adduced. Also the natural regeneration of Silver Fir has been studied. The success of conservation of Silver Fir depends on adjusted forest management treatments concerning the different ecological needs of Silver Firs at various life stages.

Key words: Silver Fir, natural regeneration, conservation, deer impact, silviculture.

In Bavaria, Silver Fir *(Abies alba Mill.)* is an important tree species which mainly occurs in mixed mountain forests and various beech vegetation types mostly at higher elevations. But also in regions which are characterized by lower water resources and higher temperature (e.g. close to the vine region in the northern part of Bavaria) Silver Fir is an important tree species in mixed beech and oak forests (fig. 1). It is assumed, that this Silver Firs is a specific fir ecotype which is often named "dry fir". The ecological and economic meaning of Silver Fir depends mainly on a high stability against windfall and other abiotic and biotic impacts. Concerning increasing temperatures during summer and decreasing rainfall during the vegetation period caused by climate change, Silver Fir is regarded to become more important. Silver Fir is well-known to use water resources in deeper grounds and so will be able to survive under dry conditions. From an economic point of view, it must be pointed out that on many sites the average increment of Silver Fir is higher compared to Spruce.

Naturally, Silver Firs would dominate or participate in 30 % of the actual Bavarian forests (total forest area in Bavaria is about 2.14 Mio hectares). However, Silver Firs currently cover about 2 % of the forest area only (about 43.000 hectares).

Most of the today's Silver Firs still grow in the Bavarian Alps and the south-eastern region "Bayerischer Wald". More than 60 % of Silver Firs in Bavaria are older than 100 years. A very insufficient amount of Silver Firs is obvious for the range of 20 to 80 years. For younger Silver Firs a stop of the downtrend is assumed. Silver Firs in Bavaria reach up to 60 metersin in height. The thickest trees reach more than 200 cm BHD and the single tree volume can achieve 60 cubic meters.

The oldest firs in Bavaria are about 600 years old. From a genetic point of view, Silver Fir in Bavaria show a distinct genetic heterogeneity which depends on the post-glacial remigration from different glacial refuges as well as on adaptation to various ecological conditions, human impact (e.g. planting and sawing) and genetic effects (e.g. genetic drift in small populations).

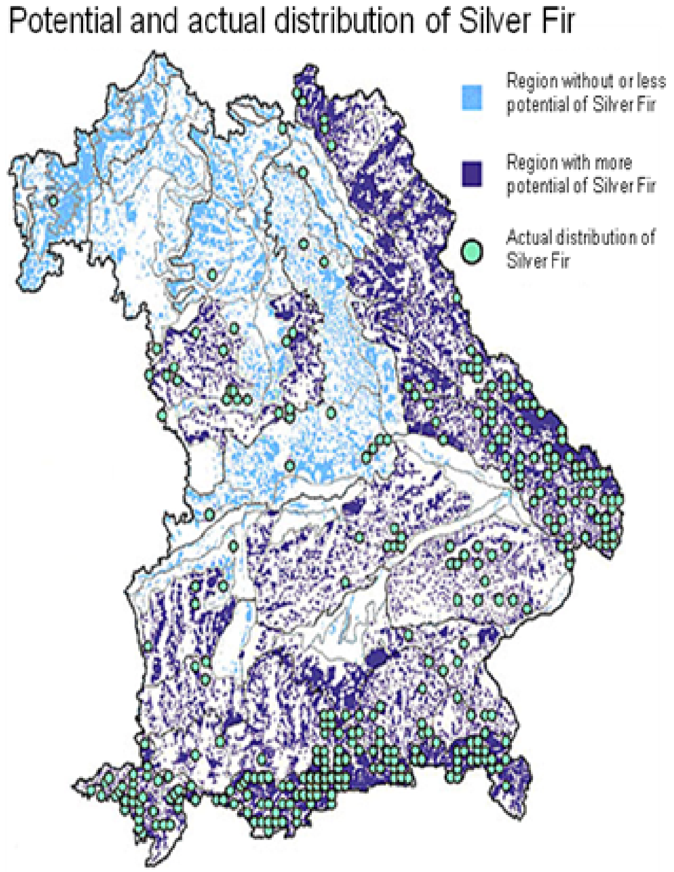

Fig. 1: Potential an actual distribution of Silver Fir in Bavaria

The great gap between actual and natural amount of Silver Fir and the lack of middle old and even younger firs in managed forests mainly depends on three well-known reasons:

1) Forest decline caused by sulfureous air pollution reduced the health of firs dramatically and many of them died back. Since the beginning of monitoring tree health in the year 1983, Silver Fir is known as the most damaged tree species. However, since air pollutions decreased from the middle of the 1990's up to now the vitality of Silver Firs increased significantly (Fig. 2).

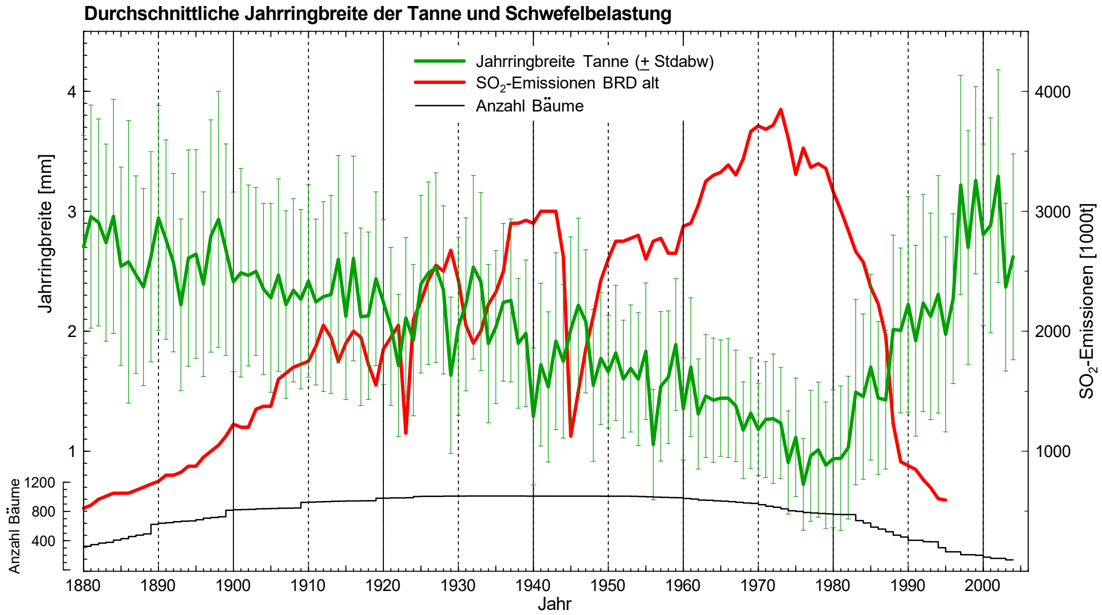

Fig. 2 (according to Elling, 2007): The figure shows the average annual increment of almost 1000 investigated Silver firs and the amount of sulfureous air pollution from 1880 to 2004. A strong correlation between increment and air pollution is obvious. After reducing pollution, the health of Silver fir increased quickly and the annual increment reached a high level even in the dry summer of the year 2003.

2) With the beginning of the so called "controlled forestry" at the end of the 19th century the amount of Silver Firs in South-Germany decreased significantly. Silver Firs extremely suffered from unadjusted silvicultural treatments especially in even-aged regeneration types (e.g. clear-cutting). Adverse climate conditions (e.g. frost) in larger gaps or open spaces are well known to be unfavourable to for succesful regeneration of Silver Fir. Successful regeneration of Silver Fir is facilitated by typical within-forest climate conditions e.g. high air moisture or wind calm. Furthermore it must be taken into account that schematic and intensive thinning concepts which nowadays are postulated for many forest types are not in accordance with the ecological needs of Silver Fir. For example, after intensive reduction of stem density in younger stands, Silver Firs are not able to change shadow-adapted needles to light-adapted needels rapidly enough. As a consequence, height growth will decrease for some years. In mixed stands especially in combination with Spruce, Silver Firs will be overgrown rapidly.

3) During the stage of regeneration, seedlings and young plants of Silver Firs are dramatically impacted by damage caused by game animals. Because of the high quality of Silver Fir buds for the nutrition of red deer and roe deer Silver Firs are preferred nutrition-plants during winter and even summer. In Bavaria, 40 % of young Firs showed a damaged terminal shoot. Up to now in some regions the impact by game animals could be reduced but in general not sufficiently enough. In stands with low Silver Fir density or in regions with high deer density a sneaking process of segregation and even complete loss of Silver Fir can still be observed. In this context it must be taken into account that Silver Fir is not able to renew a damaged terminal shoot in one year. If the terminal shoot was damaged, Silver Fir first must sprout a lateral shoot out of dormant bud and only then a new terminal shoot can grow one year later. So, a single damage or repeated damages of the terminal shoots reduces the power of competition of Silver Firs compared to other tree species (mainly Spruce) dramatically.

According to the latest forest inventory, the area of Silver Fir stands in Ukraine amounted to 124.3 thousand hectares. Basically they are concentrated in the mountainous part of Lviv, Chernivtsi and Ivano-Frankivsk regions.

As an example for foresters can serve the mixed spruce-beech-silver fir virgin forests that have survived in the Ukrainian Carpathians (Fig. 3). They serve as a model for the formation of horizontal and vertical structure of Silver Fir stands.

In Silver Fir forests of the Ukrainian Carpathians the game damage is rarely seen. The reasons for this are as follows:

- There occur predators such as wolves, lynx, bears and golden eagles.
- In the closed and pristine forests, there is little food for the deer.
- Now and then, before harsh winter with lots of snow, which can cause significant mortality of wild animals.
- Poaching is also not excluded. But its impact is local and small.

Therefore the Silver Fir in the Ukrainian Carpathians has good natural regeneration. Good natural regeneration of fir is evidenced by our data from the investigation of windthrow areas that have emerged in different regions of the Ukrainian Carpathians. We have established 42 plots to study there self-grown seedlings and advance growth, and on 30 of them were the Silver Firs.

Natural regeneration of trees is genetically and environmentally more adapted to the respective site conditions, climate and soil. Successful natural regeneration requires less effort and saves money for the creation of forest culture and care for them.

Fig. 3. The mixed spruce-beech-silver fir virgin forest in the Carpathian biosphere reserve

In general, we can conlude that the success of conservation of Silver Fir depends on adjusted forest management treatments concerning the different ecological needs of Silver Firs at various life stages. Therefore, unevenaged forest management systems, patterned after long-term irregular shelter wood systems (Femelschlag) or single-tree selection systems (Plenterwald), are strongly required. However, it must be taken into account that the successful regeneration of Silver Fir depends significantly on well adjusted deer density. Silver Firs guarantee stable, healthy, ecologically valuable precious and attractive forests.

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УДК 630*231:633.877.12 ***Проф. Е. Гуссендьорфер, д-р с.-г. наук – у-т прикладних наук, м. Фрайзінг (ФРН); доц. В.В. Лавний, канд. с.-г. наук – НЛТУ України***

Ялиця біла *(Abies alba Mill.)* у Баварії та Українських Карпатах

Як у Баварії, так і в Українських Карпатах ялиця біла (*Abies alba Mill.)* є важливим видом дерев і поширена переважно у гірських лісах. Але в Баварії вона росте також у рівнинній частині та формує мішані ялицево-дубові і ялицево-букові ліси. Екологічна та економічна цінність ялиці білої пов’язана з її високою стійкістю до вітровалів та інших несприятливих факторів довкілля. Завдяки глибокій, добре розвиненій кореневій системі вона може успішно переносити періоди тривалої посухи. Крім того, ялиця біла має у більшості типів лісорослинних умов більший приріст і запас деревини порівняно з ялиною європейською. Ялицеві ліси зараз займають у Баварії понад 43 тис. га (лише 2 % від площі лісів), хоча потенційно площа ялицевих типів лісу становить 30 %. Переважно ялицеві деревостани зосереджені в Баварських Альпах і в південно-східному регіоні «Баварський ліс». Понад 60 % ялицевих насаджень мають вік більше 100 років. Велика різниця між теперішньою і потенційною площею ялицевих лісів пояснюється такими чинниками: 1) промисловим забрудненням атмосферного повітря, найбільш чутливою до якого виявилася ялиця біла; 2) застосуванням у минулі десятиліття суцільнолісосічних рубок і труднощами природного поновлення ялиці білої на зрубах через її пошкодження пізніми весняними заморозками. Крім того, на ріст ялиці негативно вплинули надмірно інтенсивні рубки догляду в молодняках, бо після них на кілька років затримувався поточний приріст дерев ялиці через адаптацію її крони до нового світлового режиму; 3) великою щільністю дичини, яка надає перевагу поїданню верхівкової бруньки підросту ялиці білої.

В ялицевих лісах Українських Карпат спостерігається добре природне поновлення ялиці білої. Наші дослідження природного поновлення деревних порід на вітровальних ділянках показали, що її самосів і підріст був наявний на 30 з 42 досліджених ділянок. Природне поновлення деревних порід є генетично та екологічно більш пристосованим до відповідних лісорослинних умов, клімату і ґрунту. Для збереження ялиці білої важливо застосовувати вибіркову систему лісогосподарювання. Прикладом для наближеного до природи лісівництва можуть служити мішані смереково-буково-ялицеві праліси, які ще збереглися в Українських Карпатах.

Ключові слова: ялиця біла, природне поновлення, збереження, вплив дичини, лісівництво.

UDC 647.047 ***Prof. V.M. Maksymiv; assoc. prof. Yo.V. Andrashek; Ph.D. R.B. Shchupakivskyy – UNFU; assoc. prof. S.I. Bilyk – KNUCA***

STATISTICAL SIMULATION OF WOOD DENSITY CHANGES DUE TO THERMAL TREATMENT IN CARBON DIOXIDE ATMOSPHERE

The aim of the present investigation was to detect changes, and make statistical simulation, of oak (*Quercus robur*) density, due to the influence of thermal modification parameters. The reduction of the density was recorded by High-Frequency Densitometry. To achieve a comparison of the initial density and the resulting density of thermal treatment, the examination was carried out on the same sample. As a result, an adequate regression model $\Delta\rho_0 = f(T, v, \tau)$ was obtained for dry wood density changes $\Delta\rho_0$ of oak with respect to temperature T, heating rate ν, and hold-up time at treatment temperature τ. The obtained results made it possible to present visually plots of nonlinear influence of modification parameters (T, v, τ) on oak wood density changes during heat treatment in carbon dioxide atmosphere.

Key words: thermal modification, wood density, high-frequently densitometry, multiply regression, treatment temperature, hold-up time, heating rate, carbon dioxide.

Introdution. The thermal treatment of wood in CO_2 is an environmentally friendly method for wood protection. The progressive thermal degradation at high temperature leads to the reduction of hydroxyl groups. For this reason hygroscopicity, dimensional stability and durability are improved [2]. On the other hand, depending on the treatment parameters, such as maximum treatment temperature, heating rate, holding time at the maximum temperature and the medium in the atmosphere, the wood becomes more brittle, and its mechanical strength and technological properties are impaired [4]. These factors, as mentioned above, influence on the changes in dry wood density. Beside strength, hardness, calorific value and stability, a range of other physical, mechanical and technological properties of wood are determined by the density of the material [5]. In this view, it seems necessary to conduct a detailed analysis of wood density changes, write the dynamics and make statistical simulation of this process depending on the process parameters.

Materials and methods. The investigations were carried out on wood samples of one tree of the oak species (*Quercus robur*). Apience of sawn timber was planed and sawn into 6 specimens (20 x 20 x approx. 400 mm tangential x radial x longitudinal) in direction parallel to the grain. Then the middle part of each specimens were cut into 10 specimens with a dimension of 20 x 20 x 20 mm (tangential x radial x longitudinal) according to DIN 52180. The overall amount of 60 samples was placed in their original position in the board. In an upstream step of preparation all these "twin samples" were arranged in a special pattern and calibrated to achieve a high quality cross-section surface, for the measurement of density by HFD- Method. At the beginning, the wood samples were conditioned to a 7-8% equilibrium moisture content at the 20±2°C and 65% relative humidity according to ISO 554. On the one hand, equal conditions for the investigations have to be achieved, as well, as on the other hand, the moisture content of the material should be smaller than 10% before heat treatment to avoid a lot of splitting and colour differences, which may result.

In the next step, the HFD- Method was applied to measure the density of the identical specimen as mentioned above. The method is based on the propagation of continuous electromagnetic waves in a high-frequency (HF) transmitter-receiver link of an extremely small electrode system in direct contact with the wood surface that is to be investigated. The experimental setup is shown in Fig. 1. Subsequently, the specimen were treated in a temperature controlled heating unit of 5, 10 and 15 degrees per hour at three temperatures (180, 200 and 220°C) with duration of 0-2 hours at each temperature level. Each of six individual specimens were taken out when reaching and when holding the various temperature levels for 0-2 hours and replaced with dummy specimen.

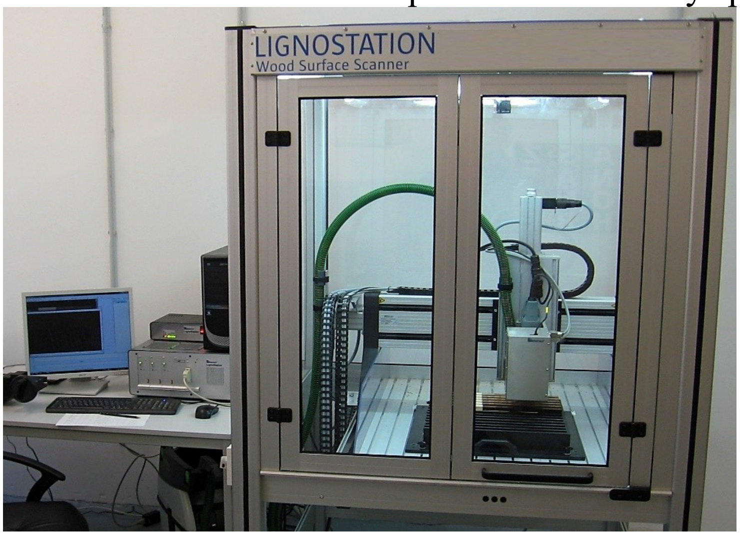


Fig. 1. Equipment for wood density measuring by HFD- method

Thus, for each temperature, the samples were removed and then remeasured with HFD-Method. The process conditions were applied and run under atmospheric pressure and in the presence of carbon dioxide. The choice of the wood specimens and materials, advanced description of the experimental setup for thermal modification in CO_2 and measurement results are given in [6].

Results and discussions. After statistical analysis of the results, blunders discarding and checking of normality distribution of the results, the choice of empirical model was carried out. By virtue of the fact that results obtained by using multiple linear regression is unsatisfying (derivable model is not adequate) the relationships among data are nonlinear and could be set out using multiple regression.

Since the central composite plans, including the second order rotatable plan, require coding factors on five levels (zero, upper and bottom levels, positive and negative values of star (±α)) their use is not possible in our case, because the planning of the experiment did not provide α. Besides, using this plan often, we obtain the significant curvature of response surface for considered dependencies. It does not allow for adequate description of regression dependence, and requires division of the research region into two experiment, as is shown in [7]. An alternative, in this case, is using multiple regression. To obtain adequate regression model that describes experimental data, the multiple regression block of software package STATISTICA 10 was used [8-19]. Using this block with setting the procedure for evaluation of regression coefficients (step-by-step with inclusion) the three-order regression dependence emerged:

$$\begin{aligned}\Delta\rho_0 \;=\; & b_0 + b_1 T + b_2\tau + b_3\upsilon + b_{12}T\tau + b_{13}T\upsilon + b_{23}\tau\upsilon + b_{112}T^2\tau + \\ & + b_{113}T^2\upsilon + b_{221}\tau^2 T + b_{223}\tau^2\upsilon + b_{331}\upsilon^2 T + b_{332}\upsilon^2\tau + b_{11}T^2 + , \\ & + b_{22}\tau^2 + b_{33}\upsilon^2 + b_{111}T^3 + b_{222}\tau^3 + b_{333}\upsilon^3\end{aligned} \qquad (1)$$

Values for significant coefficients of model (1) are presented in Table 1.

Table 1. Significant coefficients of multiple regression

Regression coefficients	Values	Student's regression t-criterion	
		calculated values	table values t $_{(0,05;5)}$
b_0	-1605,178	58,81	1,98
b_1	15,088	55,04	1,98
b_{11}	-0,034	48,94	1,98
b_{112}	-0,005	8,56	1,98
b_{331}	-0,002	14,90	1,98
b_{22}	21,476	10,08	1,98
b_2	-255,716	11,87	1,98
b_{221}	-0,127	11,93	1,98
b_{12}	2,273	10,65	1,98
b_{333}	0,010	13,69	1,98
b_{13}	0,015	12,27	1,98
b_{332}	-0,003	2,261	1,98

Coefficient of multiple determination (R^2) for equation (1) with coefficients from Table 1 equals R^2= 0, 99990491. Calculated and tabulated means for significant Student's t-criterion shown in tab. 1 also. Adequacy for equation of multiple regression in general is evaluated by Fisher's criterion; for our occurrence F=14338,95. As observed value of F-criterion exceeds the one from table, and significance level p =0.000001 the regression simulation (1) is adequate and highly significant. As previously mentioned, multiple regression assumes relationships between the variables in the equation, and a normal distribution of residuals (***observed minus predicted*** values).

If these assumptions are violated, our final conclusion may not be accurate.

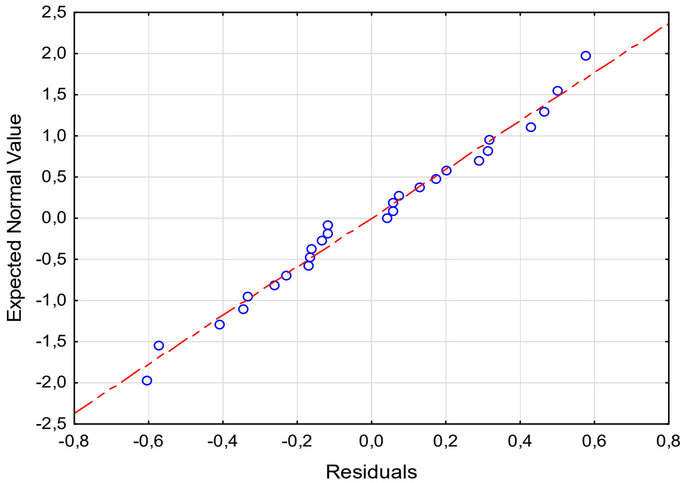


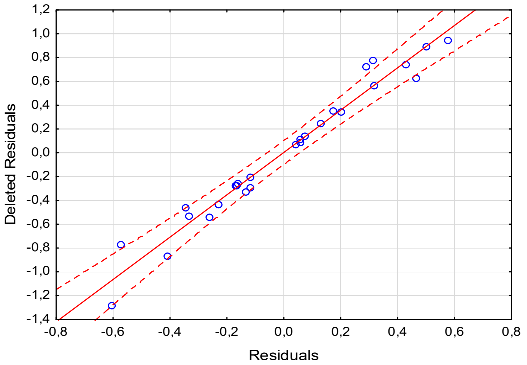
Fig. 2. Normal probability plot of residuals

The normal probability plot of residuals (Fig.2.) will give us an indication of whether gross violations of the assumptions have occurred. As can be seen from the graph, deviation of residuals points from line is inappreciable (all values fall very closely onto a straight line in the plot); it indicates normality of their distribution. Furthermore, this arrangement of residuals relatively the line attest sufficient compliance of the experimental results and the results obtained using the regression equation (2).

Adequate regression model that describes experimental data is as follows:

$$\begin{aligned}\Delta\rho_0 \;=\; & -1605{,}178 + 15{,}088\cdot T - 255{,}716\cdot\tau + 2{,}273\cdot T\tau + \\ & + 0{,}015\cdot T\upsilon - 0{,}005\cdot T^2\tau - 0{,}127\tau^2 T - 0{,}002\cdot\upsilon^2 T - , \\ & - 0{,}003\cdot\upsilon^2\tau - 0{,}034\cdot T^2 + 21{,}476\cdot\tau^2 + 0{,}010\upsilon^3\end{aligned} \tag{2}$$

To check the stability of regression coefficients residue vs. deleted residuals graph was built (Fig.3.). In view of of insignificant differences in the values of received and deleted residues, within the confidence interval of 95%, we can state that the coefficients of regression are stable and do not depend on individual experiments.



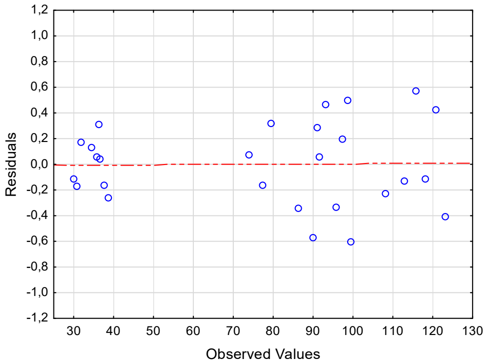


Fig. 3. Residuals vs. deleted residuals (confidence interval 95%)	*Fig. 4. Residuals and observed values*

The relationship between observed values and residuals is shown on Fig. 4. The distribution of residues do not form a homogeneous region centered around the line. It indicates the existence of nonlinear relationship between the predictors and the response function, as evidenced by the obtained regression equation (2). Moreover, Fig. 4. detects absence of outliers or groups of observations that are over- or under-predicted, which also confirm the value of a "legitimate" correlation. Graphs for dependencies $\Delta\rho_0 = f\,(T, v, \tau)$ of response surface defined by equation (2), in case when one of three variable factors is stabilized, are shown in Fig. 5-6. The graphic dependencies analysis shows that the most significant effect on the density changes of oak has a temperature factor and hold-up time. As shown in Fig. 6, increasing of modification temperature from 180 to 200°C, leads to an increase in changes, at constant hold-up time and fixed heating rate, averaging from 5.4 to 17.6%. Effect of hold-up time at given temperature modification, albeit to a lesser degree, also leads to decrease in density (Fig. 5).

However, the influence of this factor is not so significant during prolonged hold time. On the other hand, increasing of heating rate from 5 to 15 °C/h to the desired temperature modification, slows daun the rane of density decrease, although not significantly compared with the influence of two other factors.

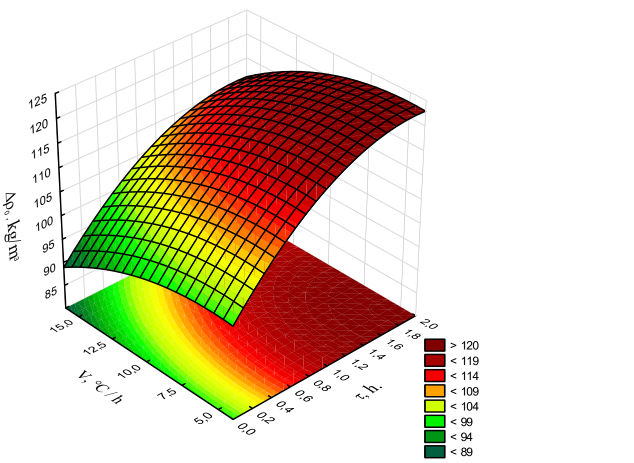


Fig. 5. Dependence of oak wood density changes from variations in heating rate, and hold-up time under the fixed temperature (180 °C) in CO_2 atmosphere

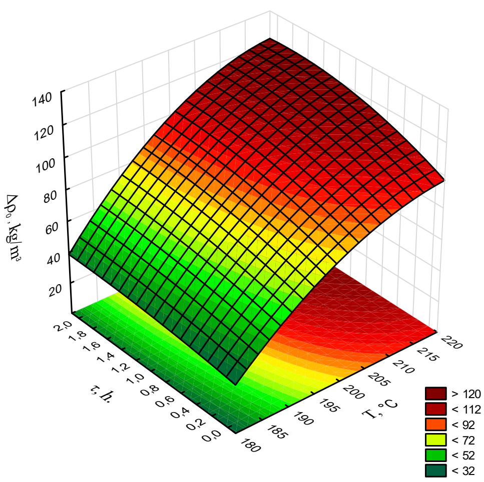


Fig. 6. Dependence of oak wood density changes from variations in temperature, and hold-up time under the fixed heating rate (5 °C/h.) in CO_2 athmosphere

Conclusions. Wood density changes in oak, due to thermal treatment in CO_2 atmosphere, was investigated. Statistical simulation of experimental data using multiply regression module was made. Consequently, has been obtained an adequate regression model $\Delta\rho_0 = f(T, v, \tau)$. Predicted results made it possible to show visual dependences of nonlinear influence of modification parameters (treatment temperature, heating rate, hold-up time) on oak wood density changes during heat modification in carbon dioxide.

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УДК 647.047 *Проф. В.М. Максимів д-р техн. наук; доц. Й.В. Андрашек, канд. техн. наук; аспір. Р.Б. Щупаківський – НЛТУ України; доц. С.І. Білик д-р техн. наук – КНУБА*

Статистичне моделювання впливу режимних параметрів процесу термічного модифікування деревини в середовищі вуглекислого газу на динаміку зміни її щільності

Досліджено зміну щільності деревини дуба в процесі термічного модифікування методом високочастотної денситометрії. З використання методу множинної регресії отримано математичні залежності зміни щільності деревини при її термічному обробленні в середовищі CO_2 та графічні залежності поверхні відклику рівнянь регресії.

Ключові слова: щільність деревини, термічне модифікування, статистична обробка, високочастотна денситометрія, множинна регресія.

UDC 674.8 *Senior teacher R.R. Kurka; prof. V.M. Maksymiv – UNFU; prof. Ya.M. Gumnitskyy – Lviv Polytechnic National University*

IDENTIFYING THE WORKING CONDITIONS OF FLAT DIE PELLET PRESS HOLES WITH PREDETERMINED GEOMETRICAL PARAMETERS

The method for determining the working capacity of flat die pellet press holes with predetermined geometrical parameters has been proposed.

Keywords: pellet press, hardwood pellet, flat die, hole geometry.

Introduction. The characteristics of a flat die in pellet press can determine its performance through the blank and effective thickness, the reliefs and the hole pattern [1]. The most important physical characteristics of a flat die are the blank thickness and the effective thickness. The blank thickness determines the overall strength of the flat die. The thicker the blank, the more it resists deflection caused by the rollers. Blank thickness should be increased instead of ligament thickness, especially in cases of repeated circumferential breakage.

Effective thickness is the length of the pellet chamber that will perform the pelleting. Effective thickness governs the amount of work the flat die will perform on a material, increasing pellet quality. Changes in material necessitate changes in effective thickness due to changes in the materials coefficient of friction [1-7].

Reliefs were developed so that increased blank thickness could be used with applications that needed thinner effective thicknesses. Currently, there are two major types of relief's: straight hole and tapered. Straight holes can be oversized, while tapered holes can be at different angles. Tapered reliefs are extended by adding a straight relief to it. These two reliefs' can be drilled in three methods: variable, non-variable, and special variable.

Standard is the normal pattern and the heavy one is used in high pressure, for hardwood waste. These patterns, when applied to various wood materials, will give different results. Every opportunity should be taken to get maximum hole count in a flat die as it increases the throughput and die life.

Research objectives – determination of movement condition of hardwood wastes, during compaction in a die hole with specific geometry.

For flat die standard hole to formulate efficiency condition by changing its basic geometrical parameters.

Let p_0, p_1, p_2 – pressure at the inlet to the channel, the output from the first and second parts; p – pressure on a layer of material; T – friction; p_b – the pressure on the lateral surface; 2φ – the angle at the top of the cone in the first section; d_1, d_2 – the diameter of the channel on the first and second sections

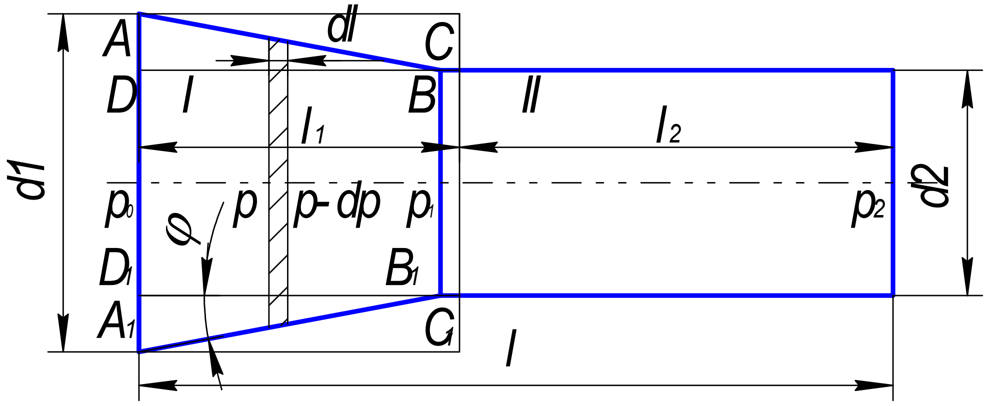


Fig. 1. Geometry of standard hole for pellet press with flat die. Design scheme

Equation for friction and pressure forces on the lateral surface of the layer can be written as: $$T = \pi dpf\xi dl\ ,\ p_b = p\xi \qquad (1)$$
where: ξ – coefficient of lateral friction; f – coefficient of external friction.

We assume that the product of the lateral pressure on the friction coefficient does not vary along the length of the channel [2]. We write the equation of equilibrium of all forces on the length of the layout of the material length. Taking as a positive trend of specific pressure movement direction of the mass of material, we obtain:

$$-\frac{\pi d_2^2}{4}dp = \pi d_2 pf\xi dl\ . \qquad (2)$$

After transformation: $$-\frac{dp}{p}dp = \frac{4}{d_2}f\xi dl \qquad (3)$$

On integrating the left side of the equation from p_1 to p_2, and right from 0 to l_2, we have: $$p_2 = p_1 \exp\left(-\frac{4}{d_2}f\xi l_2\right) \qquad (4)$$

Consider the first conical section. The expression (1) shows that the friction force and the pressure are increasing when the diameter and the length of the hole are increased because: $$T_k \le T_{ACC_1A_1} \qquad (5)$$
where: T_k – the friction in the conical section ABB_1A_1; $T_{ACC_1A_1}$ – friction in the cylinder with a diameter d_1 and length A_1B_1. On the other side of the equation (4) it is shownshows that for reducing walues in the bursting pressure of the material through the die hole it is necessary to reduce the channel length and increase in diameter, so:

$$P_1 := P_{1,k} \le P_{1,DBB_1D_1} \qquad (6)$$

where: P_k – the pressure in the conical section, ABB_1A_1 – pressure in a cylinder with a diameter d_2 and length l_2. Then condition of equilibrium can be written as follows:

$$T_k \le T_{ACC_1A_1} = P_1 \le P_{1,DBB_1D_1} \qquad (7)$$

$$-\frac{\pi d_2^2}{4}dp = \pi d_1 pf\xi\frac{dl}{\cos\varphi}, d_1 = d_2 + 2l_1\tan\varphi \qquad (8)$$

After transformation we obtain: $$-\frac{dp}{p}=4\frac{d_2+2l_1\tan\varphi}{d_2^2}f\xi\frac{dl}{\cos\varphi} \qquad (9)$$

On integrating the left side of the equation from p_0 to p_1 and the right one – from 0 to l_1, we have: $$\ln\left|\frac{p_1}{p_0}\right|=-4\frac{d_2+2l_1\tan\varphi}{d_2^2\cos\varphi}. \qquad (10)$$

Than: $$p_1=p_0\exp\left(-4f\xi l_1\frac{d_2+2l_1\tan\varphi}{d_2^2\cos\varphi}\right). \qquad (11)$$

From formulas (4) and (11), we obtain:

$$p_2=p_0\exp\left(-4f\xi\left(\frac{l_2}{d_2}+l_1\frac{d_2+2l_1\tan\varphi}{d_2^2\cos\varphi}\right)\right) \qquad (12)$$

A necessary condition for the movement of material through the hole is the excess pressure forces needed to overcome the material force of friction is:

$$\frac{1}{3}\pi\left(d_1^2+d_1d_2+d_2^2\right)\left(p_0-p_1\right)+\pi\frac{d_2^2}{4}\left(p_1-p_2\right)>$$
$$>\pi\left(d_1+d_2\right)\frac{l_1}{\cos\varphi}f\xi\left(p_0-p_1\right)+\pi d_2l_2f\xi\left(p_1-p_2\right) \qquad (13)$$

And $$\left(\frac{1}{3}\left(d_1^2+d_1d_2+d_2^2\right)-\left(d_1+d_2\right)\frac{l_1}{\cos\varphi}f\xi\right)\left(1-\exp\left(-4f\xi l_1\frac{d_2+2l_1\tan\varphi}{d_2^2\cos\varphi}\right)\right)>$$
$$>\left(d_2f\xi l_2-\frac{d_2{}^2}{4}\right)\left(1-\exp\left(-\frac{4}{d_2}f\xi l_2\right)\right) \qquad (14)$$

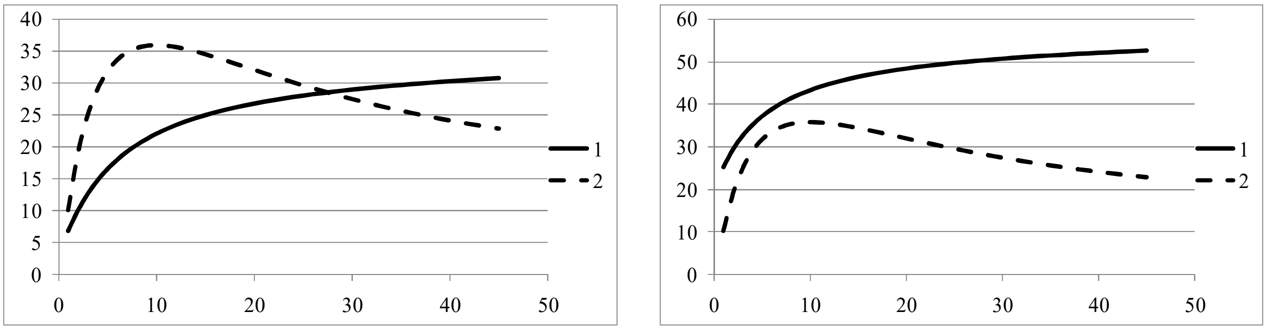
To determine the efficiency of the die hole, we performed a computational experiment. For the basis is taken experimentally obtained parameters of granulation in a single channel pelleter [3].

Initial data for numerical experiment are as follws:

- coefficient of lateral friction, $\xi=0{,}6$;
- coefficient of external friction, $f=0{,}39$;
- diameter of cylindrical areas, d_2 = 6; 7; 8; 9;
- diameter of the cone base areas, $d_1=1{,}0\div1{,}5\cdot d_2$;
- the angle at the top of the cone on the first plot, $\varphi=5^o\div50^o$;
- the recommended [4] length of the hole L, L = 3,25 d_2.

Tu outline limits change of basic geometric parameters of the standard hole geometry (Fig. 1) relation is used (14). Based on initial data four computational experiments for diameters of cylindrical parts were held. Fig. 2, shows the correlation of forces acting on the material in order to push through the channel (number 1) and the forces that resist movement (number 2). The experiment was conducted in relative units. Therefore, the results can only serve to define boundaries of die hole performance with given geometry. After a series of experiments, in which the above mentioned factors were analyzed, the generalization of the limits of performance of the die hole for a given coefficient of lateral friction ξ=0.6 and external friction *f*=0.39. Adequacy of the proposed model illustrated Fig. 2 a, b.

The increase in the total length L, hampers material transfer in the hole, and, at a certain threshold value for the given conditions (L = 38 mm) – Fig.2b, the channel becomes inoperable. For fixed values $d_1=1{,}0\div1{,}5\cdot d_2$ of the diameter of base conic section with step 0.2 hole performance interval is defined in which the left part of the relationship (11) is greater than the right. Family united in set intervals, gives as an idea to build the performance area with preserving mobility criterion of the material in the hole. Figure 3 shows the four zones of performance for die hole with fixed diameter of cylindrical section. Each zone is bounded be above quantity and is equal $t = 1{,}5 \cdot d_2$. This is not expedient to use the base diameter of the cone channel larder than holes in the die step t.



a) b)

Fig. 2. Analysis the performance of die hole by changing its overall length:
a) hole functioning within the angle $\varphi = 5^{\circ} \div 26^{\circ}$ at L = 26 mm,
b) hole capacity is completely lost at L = 38 mm

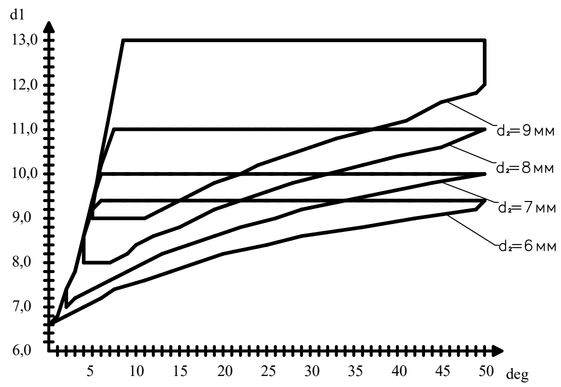


Fig. 3. Working condition for fixed diameter die hole in absolute units.

Conclusions: With prolonged use of die, depth and shape of the original tapered holes become distorted. We can grind flat die to a smaller thickness, but in general, it will reduce the overall length of the channel and change the lengths ratio of conical and cylindrical parts of hole. The above formulas show that even while maintaining the movement conditions in the channel, pressing material particles may not work. So when we may produce flat pellet die with such geometrical parameters of holes to further flatness is recovered. The proposed method can identify the limits of working capacity for known hole geometry. This will ensure the nominal conditions of pressing the mixture and keep the condition of material motion in the die hole during the whole operation.

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УДК 674.8 ***Ст. викл. Р.Р. Курка; проф. В.М. Максимів, д-р техн. наук – НЛТУ України; проф. Я.М. Гумницький, д-р техн. наук – НУ «Львівська політехніка»***

Ідентифікація умов працездатності каналів із заданими геометричними параметрами в грануляторі із плоскою матрицею

Запропоновано метод визначення працездатності отворів плоскої матриці гранулятора із заданими геометричними параметрами.

Ключові слова: гранулятор, паливні гранули, плоска матриця, геометрія каналу матриці.

UDC 674.028.9.004.15:519.216.3 ***Assoc. prof. B.Ya. Kshyvetskyy – UNFU; prof. M.G. Chausov – National University of Life and Environmental Sciences of Ukraine***

STRESS MODELLING FOR THERMOPLASTIC ADHESIVE WOOD JOINTS

The paper concerns modelling stresses in thermoplastic adhesive wood joints. As a result of modelling heat-and-mass transfer, the distribution pattern of normal and tangential stresses was revealed and their influence on the durability of thermoplastic adhesive wood joints was shown.

Keywords: adhesive joint, moisture, heat transfer, stress-strain condition, strain and relaxation processes, stress components.

The mathematical calculations for moisture transfer which are presented in the work [1] enabled to mathematically describe the effect of cyclic variation in moisture content on thermoplastic adhesive wood joints. The studies presented in the works [2, 3, 4] show that the cyclic variation in moisture and temperature results in increased stresses in thermoplastic adhesive wood joints, also this causes changes in the stress-strain condition. The amount of stresses that develop in the adhesive joint will depend on many factors of which physical and mechanical properties of the material to be glued, that is wood, and the material that glues, that is an adhesive, are of paramount importance. The effect of cyclic variation in moisture content and temperature on the adhesive wood joints during their service is responsible for changes in the stress-strain condition both of the wood and the glue line.

Thermoplastic adhesive wood joints, as contrasted with thermosetting ones, are able to relax the stress-strain condition to a certain point of time. This is possible due to elasticity of the glue line whose relaxation limits are determined by physical and mechanical properties of the thermoplastic glue film [5].

The stress-strain condition as well as relaxation processes that take place in adhesive wood joints are directly related to the change in wood joints strength and are responsible for their durability. This is supported by the works devoted to the issue of strength and durability of thermoplastic adhesive wood joints [6, 7, 8]. To describe mathematically the deformation and relaxation processes that occur in thermoplastic adhesive wood joints is not an easy task; however, it must be done since this would provide a means of detailed studying and modelling the processes involved.

In order to model the distribution of stress-strain condition of glued wood with thermostressed properties taken into account, we can resort to the task of thermoelasticity for plane strain which is characterized by the following displacement field

$$U_1 = U_1(x_i, y), \quad U_2 = U_2(x_i, y), \quad U_3 = 0 \tag{1}$$

where U_i =(1,2,3) are displacement components.

Consider the task of stress-strain distribution in the region

$$\Omega = \sum x = (x_{i,}y): \ x\epsilon[0,l_1] \quad x_2\epsilon[0,l_2] \tag{2}$$

where l_1, l_2 are the geometry of the specimen.

The task of transposing stress-strain condition of glued wood consists in the following: it is necessary to find the solution to the system of differencial equilibrium equations which takes the form: $\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = 0; \qquad \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = 0$ (3)

where σ_x, τ_{xy} are components of normal and tangential stresses.

The diagram of adhesive joint in calculating the stress-strain condition is shown in Fig. 1

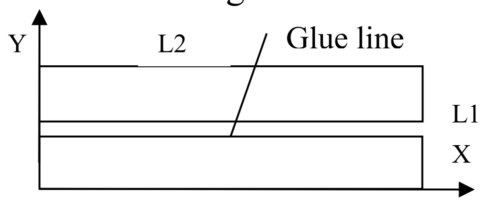

Fig. 1. Diagram of adhesive joint in calculating the stress-strain condition

The relationship between the components of stresses and strain takes the form:

$$\sum x = \frac{1}{E_1}\sigma_x - \frac{V_{21}}{E_2}\sigma_y + \alpha_x \Delta T + \beta_2 \Delta U; \tag{4}$$

$$\sum_y = -\frac{V_{21}}{E_2}\sigma_x + \frac{1}{E_2}\sigma_y + \alpha_y \Delta T + \beta_2 \Delta U; \tag{5}$$

$$\gamma_{xy} = G_{12} \cdot \tau_{xy}$$

where: $E_i(t, U)$, $U_{iy}(t, U)$, $G_i(t, U)$ are elastic moduli, Poisson's ratios and shear moduli for wood material with consideration for its anisotropic properties which are dependent on temperature and moisture; α_x, α_y; β_x, β_y are coefficients of thermal and moisture-induced deformations of the material.

The functions $T(x, \tau)$ and $U(x, \tau)$ are determined by solving the equations represented. The relationship between the components of strain tensor $\sum x$, $\sum y$, γ_t and displacement (1) takes the form $\sum x = \frac{\partial U_1}{\partial x}; \sum y = \frac{\partial U_2}{\partial y}; \tau_{xy} = \frac{\partial U_2}{\partial x} + \frac{\partial U_1}{\partial y}$ (6)

The components of strain tensor satisfy compatibility equations which in tensor form will look like: $\varepsilon_{ij,kl} + \varepsilon_{kl,ij} - \varepsilon_{ij,it} - \varepsilon_{ik,je} = 0(i, j, k = x_1 y_1 t)$ (7)

Boundary conditions for solving the mathematical model (1-7) can be represented as:

$$\begin{aligned}
&\sigma_x = 0; x = (0, l_1); \ \sigma_y = 0; y = (0, l_2); \\
&\tau_{xy} = 0, x = (0; l_1); \ y = (0; l_2) \qquad (8) \\
&\sigma_x^{(1)} = \sigma_x^{(2)} x\epsilon(0; l_1); \ \sigma_y^{(1)} = \sigma_y^{(2)}, y = l_2/2; \\
&\tau_x^{(1)} = \tau_x^{(2)} x\epsilon(0; l_1); \ y = l_2/2
\end{aligned}$$

The strain field can be expressed through the degree of freedom for strain field of displacements and it will be related to the displacement strain. In view of the equation (based on the Hooke's Law) whose coefficients will create a matrix, we establish relations first to the stress field, then to the strain field and after that between the stresses and the degree of freedom in the joints. Presented in Figs. 2-4 are the results of numerical experiment for determining the components of normal stresses σ_x and σ_y as well as tangential stresses τ_{xy} for pine wood (ρ=460 kg/m^3). The stresses were studied in the area of gluing and at distances of 0.5 mm and 1mm away from this area.

The components of stresses σ_x are shown in Fig. 2 while the components of stresses σ_y are given in Fig. 3. The curve represented as "—" corresponds to the stress at the 0.5 mm distance from the glueing area, the curve represented as "–––" is for the 1 mm distance, and the curve represented as "–·–·–" is for the area of glueing.

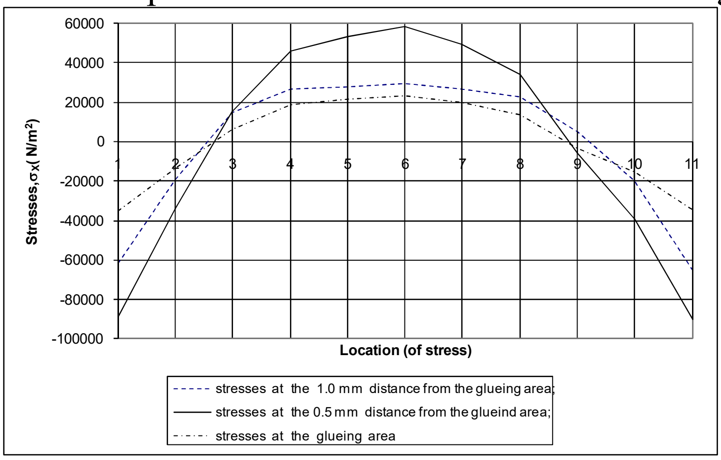

Fig. 2 Distribution of normal stresses σ_x

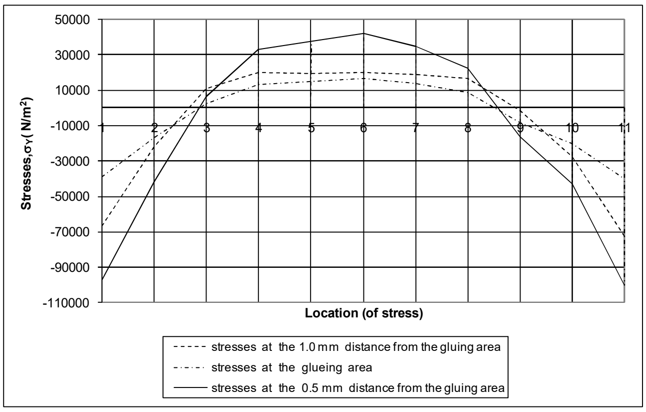

Fig. 3 Distribution of normal stresses σ_y

The analysis of the stress curves for the cross-section of the glued specimen suggests that the components of stresses σ_x and σ_y take the maximum value in the middle part of the geometrical section. For the 0.5 mm distance the components of the normal stresses σ_x and σ_y are greater that similar components in the glueing area and at the 1 mm distance. Besides, one can observe changes in normal stresses at the cross-section, but one can also observe a destructive character of normal stresses in the middle part of the cross-sectional area of glueing. Due to the difference in the magnitudes of shrinkage factors for wood and adhesive, compression stresses are found to develop in the 0.5 mm and 1 mm distances from the glueing area. Because of such stresses, nonuniform distribution of the temperature and moisture in the glued wood is conditioned by variation in ambient temperature. The analysis of graphically-represented relationships of normal stress components points to nonuniform distribution of σ_x and σ_y, which is accounted for by the influence of anisotropy as well as mechanical-and-thermophysical properties of the wood and adhesive (Young's modulus, Poisson's Ratio). The uneven penetration of adhesive into the wood in the area of glueing is also responsible for nonuniform distribution of normal stress components. The qualitative characteristics of normal stresses do not change as the distance from the glueing area increases; however, their quantitative parameters become different. In particular, the shorter directions are to the central axis of the specimen, the smaller values of the normal stresses are, the maximum value decreasing by 26 %.

This is attributable to increased uniformity of thermo-physical and mechanical properties of the glued wood. Fig. 4 shows the components of tangential stresses for adhesive wood joints in the glueing area, at the 0.5 mm distance, and at the 1.0 mm distance from the glueing area. The analysis of graphically-represented relations of tangential stresses points to the complicated and nonuniform pattern of their distribution across the glueing area and in the near-surface regions. In quantitative characteristics, the stresses τ_{xy} are significantly less than normal stresses, but their distribution is much more complicated and nonuniform (Fig. 4).

This is particularly true for the stresses τ_{xy} in the glueing area. Uneven distribution of adhesive, diffusion characteristics, surface roughness-all these result in fluctuating character of tangential stresses. Uniform distribution of stresses τ_{xy} is observed in the near-surface regions, but for all cases, the tangential stresses take maximum values in the near-surface regions of the glued wood and their distribution becomes more uniform in character.

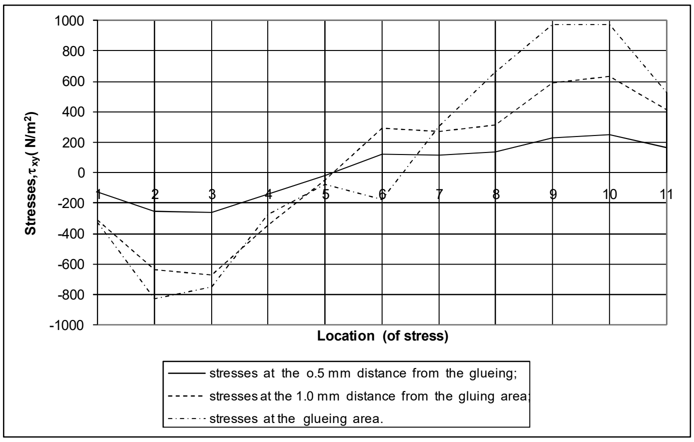

Fig. 4. Distribution of tangential stresses τ_{xy}.

To sum it up, it may be noted that the results of modeling heat-and-mass transfer make it possible to perceive the distribution of normal and tangential stresses in thermoplastic adhesive wood joints in different planes. It was found that normal stresses in the adhesive wood joints take maximum values in the middle part of the geometrical section of the specimen.

The stresses take the highest values at the 0.5 mm distance from the glueing area, which points to the fact that the glue line elasticity allows for stress relaxation in the glueing area, and, in so doing, it is possible for stresses to be transferred, in part, into the wood. This will have a beneficial effect on the durability of adhesive wood joint, which is supported by experimental investigations of wood deformation properties as well as physical-and-mechanical properties of the thermoplastic glue line.

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УДК 674.028.9.004.15:519.216.3 ***Доц. Б.Я. Кшивецький, канд. техн. наук – НЛТУ України; проф. М.Г. Чаусов – НУ біоресурсів і природокористування України***

Моделювання напружень у термопластичних клейових з'єднань деревини

Наведено моделювання напружень у термопластичних клейових з'єднаннях деревини. За результатами моделювання тепломасоперенесення встановлено розподіл нормальних та тангентальних напружень та виявлено їх вплив на довговічність термопластичних клейових з’єднань деревини.

Ключові слова: клейове з'єднання, вологість, теплоперенесення, пружно-деформаційний стан, деформаційні та релаксаційні процеси, компоненти напружень.

UDC 658.527.011.56 ***Assoc. prof. R.Ya. Orikhovskyy – UNFU***

THE INFLUENCE OF HARDWARE RELIABILITY ON TECHNOLOGICAL INDEXES OF EFFICIENCY

Influence is studiedof reliability of hardwares on the technological indexes of efficiency of functioning of automated control the system by technological processes. The modern methods of determination of reliability are examined for the decision of tasks of increase efficiency of functioning of the automated production systems on the enterprises of industrial forestry complex. Refuses in technological lines influence on reliability through casual character of sizes and certain descriptions of purveyances, parameters of machine-tools and their knots, instruments. Reliability of equipment considerably influences on the actual productivity of the automated production systems. The decline of reliability predetermines the considerable decline of the actual productivity of the automated production systems and decline of stability of technological operations. To promote reliability of the automated pro-

duction systems expediently by development of charts of arrangement of equipment, structurally self-reactance optimization, structural backuping and imitation design.

Keywords: reliability of hardwares, technological indexes of efficiency, control the system by technological processes, imitation design, structurally self-reactance optimization, backuping is automated.

Substantially influences on efficiency of functioning of automated control the system by technological processes in industry of woodworking reliability of hardwares, production equipment, management facilities. Unreliability of technique, failings in organization of labour, the factors of external influence draw the losses of time of functioning of technological equipment. Influence of reliability of hardwares on the technological indexes of efficiency shows up in that the consequences of refuses of hardwares are represented on the conduct of management object (Fig.1). Efficiency of the automated production systems is determined by technological, organizational and by economic indicators.

The technological indexes of efficiency are determined in technological units and represent such sides of functioning of the automated technological complex: amount of the manufactured products; quality of the manufactured products; amount of the consumed raw material, materials, energy, fuel; use of technological equipment. ***The organizational indexes*** of efficiency represent the labour costs of personnel of the automated technological complex on the production of goods and determined in units of labour costs (m/hrs), that is determined in times of calendar.

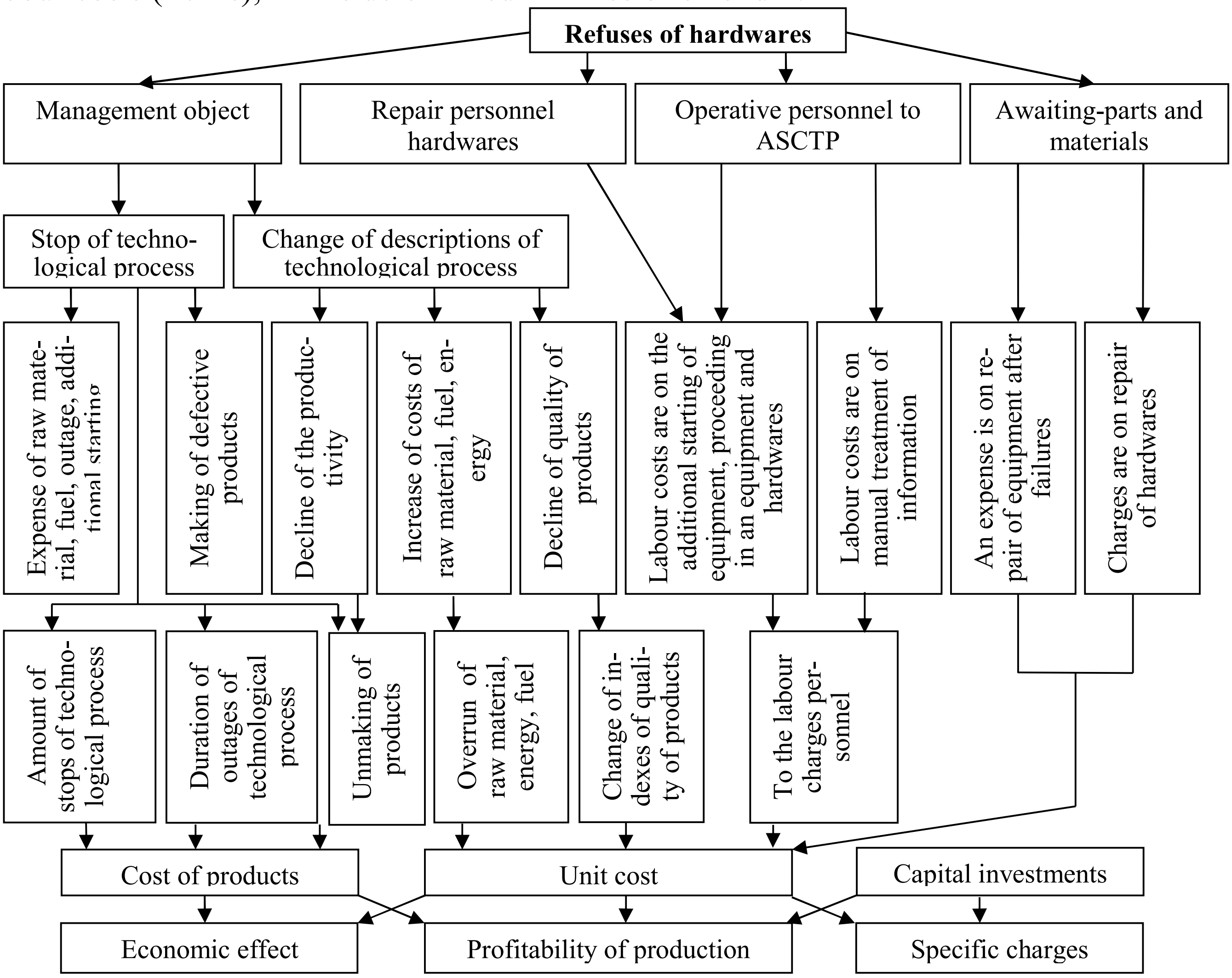

Fig. 1. Influence of failures of hardwares on the indexes of efficiency to the automated system of the control by technological processes

The economic indexes of efficiency represent the economic results of functioning of the automated technological complex and is determined in monetary items or in units which determine the degree of accordance of these results to the costs.

The technological indexes of efficiency, which describe the amount of the manufactured products, can be determined for calendar unit time, for work unit of equipment, for unit of the cosumed materials, raw material et cetera for continuously discrete technological processes these indexes can be determined for the cycle of treatment. Indexes which describe quality are often determined as a fate of products, which is made the certain sorts of quality in attitude toward all of products of made for calendar time unit, unit of work of equipment. Indexes which characterize the use of equipment (amount of the forced stops, total duration of outages) belong to calendar time. As a result of emergency failures of hardwares there is a damage of equipment or stopping of technological process, as a result of technological refuses descriptions of technological process are worsened without his stop. The emergency failures of hardwares can influence on: amount of products which is made, as a result of the forced costs of working hours on the outage of equipment and transients of his stop and starting; quality of products is as a result of possible shortage at transitional processes of starting and especially stop; cost of energy, raw material, materials, fuel et cetera in case of stopping, outage and starting of equipment; use of equipment; coefficient of the use of equipment. The technological refuses of hardwares can influence on: to the unmaking products; decline of its quality, issue of defective products; increase of cost of energy, raw material, materials, fuel.

Reliability of hardwares of the automated system of the control by technological processes is determined such constituents: faultlessness, by fitness to repairs, by longevity, by property to keep the set descriptions during the set term. Faultlessness, determined as. Important the factor of violation of the set terms of co-operation between machine-tools, mechanisms in a technological line is cyclic instability of parameters of work which shows up during exploitation of technological line. Therefore ground of reliability of the automated production systems from positions only a wear is insufficient. Failures in technological lines influence on technological reliability through casual character of sizes and certain descriptions of purveyances, parameters of machine-tools and their knots, instruments. For renewal, functioning of the automated production system is required set time. The charges of time are expended in proceeding in normal work of equipment increase duration of intervals of issue and reduce the actual productivity of technological lines [1-12]. These undesirable consequences grow with the increase of power of equipment and rev-up flowing of technological processes.

For the decision of problem of reliability of the automated system of the control by technological processes it is suggested to decide such modern tasks:

1. To develop the methods of forming of the scientifically grounded requirements to reliability of industrial hardwares of different types recognition possibility of their backuping, use of these facilities in different the automated system of the control by technological processes. To develop the methods of optimization of technical maintenance of facilities of the automated system of the control by technological processes and microprocessors, utilize a computer technique, for providing of rational level of centralization of service and warehousing of awaiting-parts, awaiting-parts.
2. To analyze possibilities and wide use of vehicle and programmatic methods of control and diagnostics of good condition of hardwares of the automated system of the control by technological processes. To create scientific and engineering's bases of reliable computer-aided of difficult facilities and control the system design.To execute a supervision and calculations of actual reliability of mechanisms indexes and built on in the conditions of exploitation together with analogical researches of the productivity and stability.
3. To promote reliability of the automated production systems expediently with the use of the structural backuping, development of charts of arrangement of technological lines, structurally self-reactance optimization and imitation design.

Decision of the indicated tasks next to other technical and organizational measures, will enable considerably to improve reliability of the automated system of the control by technological processes on the whole.

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УДК 658.527.011.56 ***Доц. Р.Я. Оріховський, канд. техн. наук – НЛТУ України***

Вплив надійності технічних засобів на технологічні показники ефективності

Вивчено вплив надійності технічних засобів на технологічні показники ефективності функціонування автоматизованих систем керування технологічними процесами. Розглянуто сучасні методи визначення надійності для вирішення завдань підвищення ефективності функціонування автоматизованих виробничих систем на підприємствах лісопромислового комплексу. Встановлено,що відмови у технологічних лініях впливають на надійність через випадковий характер розмірів і певних характеристик заготовок, параметрів верстатів та їх вузлів, інструментів. З'ясовано, що надійність обладнання значно впливає на фактичну продуктивність автоматизованих виробничих систем. Виявлено, що зниження надійності зумовлює значне зниження фактичної продуктивності автоматизованих виробничих систем і зниження стабільності технологічних операцій. Встановлено, що підвищувати надійність автоматизованих виробничих систем доцільно за допомогою розроблення схем компонування обладнання, структурно-параметричної оптимізації, структурного резервування та імітаційного моделювання.

Ключові слова: надійність технічних засобів, технологічні показники ефективності, автоматизовані системи керування технологічними процесами, імітаційне моделювання, структурно-параметрична оптимізація, резервування.

UDC 674.093.6:674.061.2 ***Assist. Ya.V. Matsyshyn; assoc. prof. V.O. Mayevskyy; stud. A.M. Del Rio – UNFU; assoc. prof. S.I. Bilyk – KNUCA***

SPECIALIZED SOFTWARE FOR SIMULATION OF LUMBER CROSS-CUTTING PROCESS

A specialized software "SAWing lumber" which simulates the process of cross-cutting of lumber into dimension stock (blanks) was developed, guided by the decision of fuzzy expert system that concerns the choice of the current cross cutting pattern. Classes diagram as well as, the work algorithm and rules of use of software interface are provided. The process of cross-cutting into blanks is simulated with the help of software. Simulation results confirmed the adequacy and the practical value of the software.

Keywords: software, simulation, lumber, cutting, blanks, non-defective pieces, cutting pattern, expert system, fuzzy logic.

The topicality of problem. In order to research and analyze various technical processes, objects and systems, the simulation process has been increasingly applied for this during past decade. In the case when the researched object is subjected to mathematical description, the analytical (mathematical) modeling is used, and when it is poorly formalized, then it is subjected to simulation modeling. Sn simulation modeling, the researched system (object) is replaced by a model which accurately describes real system. Aimed at obtaining information about system, the experiments are conducted with real system [1, 2]. In simulation it is necessary to select systems that simulate not only the physical (or other) nature of the particular subject area, but the mechanism of the human mind to solve specific problems, these are so-called expert systems (ES) [2].

In the ES, the main attention is paid to the reproduction of problem-solving method by means of computer technology used by the expert as an implementation of expert's thinking. In the paper [3], the ES is developed with the usage of fuzzy logic in order to take effective current decisions regarding the selection of lumber cross-cutting scheme (non-defective pieces) into blanks. For taking such a decision, fuzzy expert system (FES) is guided by the following factors: the size of defect less raw materials obtained when cutting (Z), a number of actually sawn out blanks of each size - quality group (Q) and the expected number of non-defective pieces of a certain length (N).

The result of FES usage is the determination of numerical value of blank priority in cutting (P). However, individual current solution of this system makes it impossible to analyze the process of cutting as a whole. Such analysis can be conducted by simulating the cutting process with the help of FES from entry point of the first non-defective pieces cutting areas until the point when blanks are sawn out.

In order to solve this problem it is appropriate to create a specialized software that would allow us to conduct a simulation. It is necessary to mention that during the operation of the software after every decision to saw out a specific blank it is important to enumerate variables that govern the FES.

Thus, **the aim of the paper** is to create a specialized software for simulation process of lumber cutting on the basis of decisions taken by FES [3].

The development of specialized software. Software SAWing_lumber (programming environment – Eclips Ide Gallileo, programming language - Java, jdk 1,6), developed in UNFU, and created for simulation modeling of cross-cutting lumber into blanks. Classes diagram developed by specialized software SAWing_lumber is shown in Fig. 1 and general block scheme of the algorithm of its operation is provided in Fig. 2.

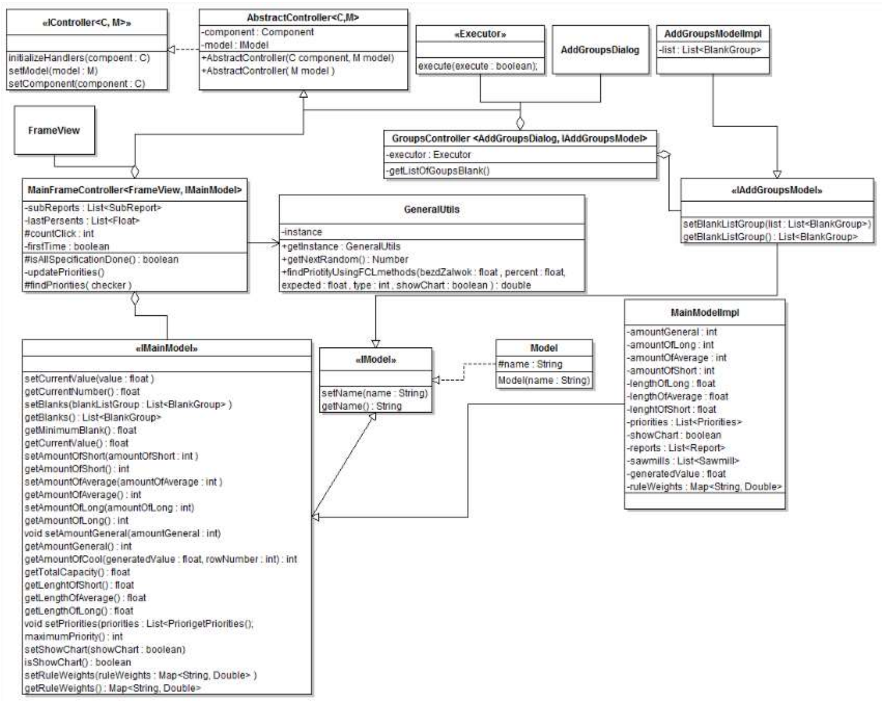


Fig.1. Classes diagram of specialized software SAWing_lumber

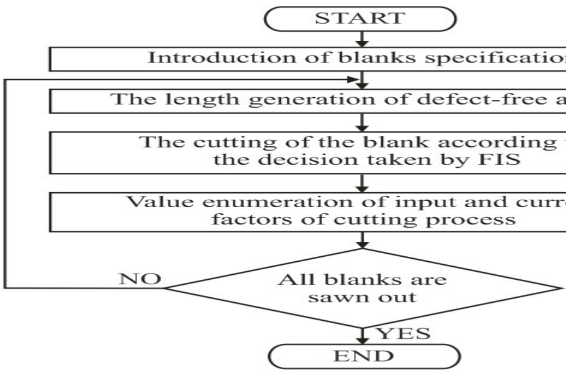


Fig.2. The block-scheme of the algorithm of software SAWing_lumber operation for simulation process of lumber cross-cutting on blanks

As can be observed from the block scheme (Fig. 2), before the beginning of simulation, the specification of blanks should be entered. Firstly, we choose the number of groups of blanks to be sawn out in the main software box of SAWing_lumber (Fig. 3) and then enter their dimensional characteristics and volume (quantity).

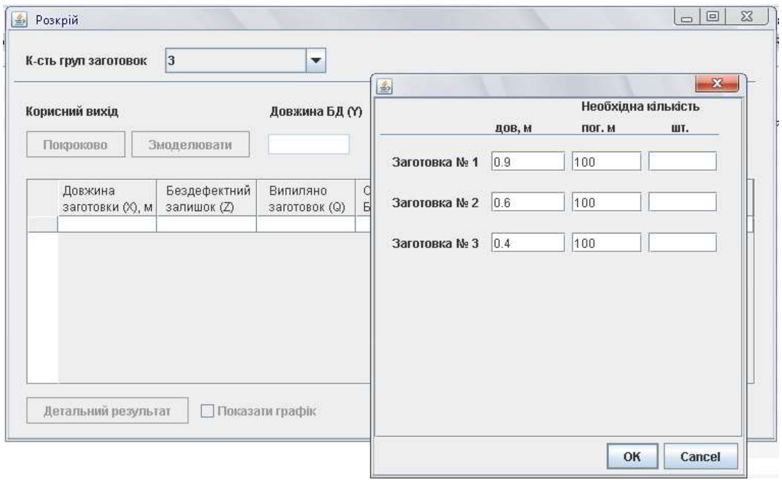


Fig.3 The dialog box for entering of blanks specification

After entering the blanks specifications, one has to proceed to simulation modeling process. The developed software SAWing_lumber allows conducting of simulation modeling in incremental and automatic modes. Incremental mode (Fig. 4) is implemented by pressing the button "Покроково". After each pressing the button "

Покроково" with the given range of lengths of non-defective pieces single value of its length is being generated. Then, the blanks priorities are being determined and the decision to saw out blank the priority for which will be the largest is taken. In this mode, it is possible to monitor the changes in the value of linguistic variables Z, Q, N at any step in the simulation process, with the help of which a numerical priority value P is determined.

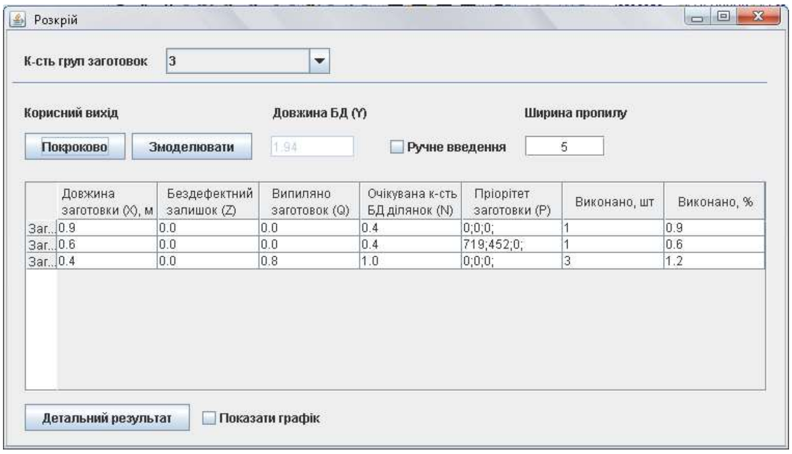


Fig. 4. View of the main box in incremental mode

In automatic mode (button "Змоделювати"), the program SAWing_lumber automatically generates the lengths of non-defective pieces and models the process of cutting into blanks until the specification of blanks is completed (Fig. 5).

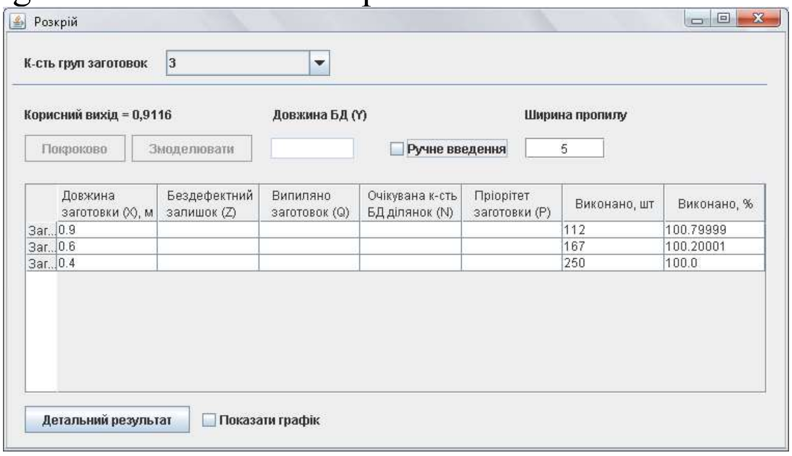
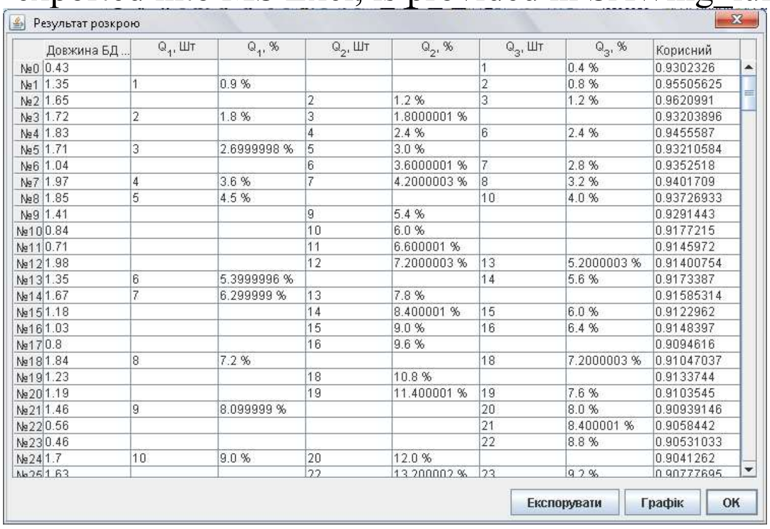


Fig. 5. View of the main box in an automatic mode

After modeling, the index value of specified blanks output from non-defective pieces is obtained. The possibility to examine detailed results of cutting (Fig. 6), which can be exported into MS Exel, is provided in SAWing_lumber.



Результат розкрою

	Довжина БД ...	Q_1, Шт	Q_1, %	Q_2, Шт	Q_2, %	Q_3, Шт	Q_3, %	Корисний
№0	0.43					1	0.4 %	0.9302326
№1	1.35	1	0.9 %			2	0.8 %	0.95505625
№2	1.65			2	1.2 %	3	1.2 %	0.9620991
№3	1.72	2	1.8 %	3	1.8000001 %			0.93203896
№4	1.83			4	2.4 %	6	2.4 %	0.9455587
№5	1.71	3	2.6999998 %	5	3.0 %			0.93210584
№6	1.04			6	3.6000001 %	7	2.8 %	0.9352518
№7	1.97	4	3.6 %	7	4.2000003 %	8	3.2 %	0.9401709
№8	1.85	5	4.5 %			10	4.0 %	0.93726933
№9	1.41			9	5.4 %			0.9291443
№10	0.84			10	6.0 %			0.9177215
№11	0.71			11	6.600001 %			0.9145972
№12	1.98			12	7.2000003 %	13	5.2000003 %	0.91400754
№13	1.35	6	5.3999996 %			14	5.6 %	0.9173387
№14	1.67	7	6.299999 %	13	7.8 %			0.91585314
№15	1.18			14	8.400001 %	15	6.0 %	0.9122962
№16	1.03			15	9.0 %	16	6.4 %	0.9148397
№17	0.8			16	9.6 %			0.9094616
№18	1.84	8	7.2 %			18	7.2000003 %	0.91047037
№19	1.23			18	10.8 %			0.9133744
№20	1.19			19	11.400001 %	19	7.6 %	0.9103545
№21	1.46	9	8.099999 %			20	8.0 %	0.90939146
№22	0.56					21	8.400001 %	0.9058442
№23	0.46					22	8.8 %	0.90531033
№24	1.7	10	9.0 %	20	12.0 %			0.9041262
№25	1.63			22	13.200002 %	23	9.2 %	0.90777695

Експорувати Графік OK

Fig. 6. View of desktop window with the detailed results of lumber cutting on blanks

Simulation of cross-cutting lumber by means of the developed software SAWing lumber. In order to check the adequacy of the software process operation, the process of lumber cutting (non-defective pieces) is modeled on blanks of three typical sizes l1, l2, and l3. The length of the first two blanks is accordingly preset l1 = 1.2 m and l2 = 0.8m and the length of the third blank will be changed l3 = (0.2; 0.4; 0.6 m). In the process of simulation modeling it is necessary to analyze the dependence of the coefficient of specified yield blanks on their specification. According to the accepted specification, it is necessary to saw out blanks of three typical sizes in such amount: Q1 = 200 lm; Q2 = 200 lm; Q3 = 200 lm. The width and thickness of blanks is identical, so the number of blanks to be sawn out is provided in linear meters. The lengths of non-defective pieces are generated accidentally from the range: 0.2 ... 2.0 m. Simulation results are summarized in Table. 1 and are shown in the diagram (Fig. 7). In order to reduce the influence of accidental distribution of lengths of non-defective pieces, the index of the specified blanks output is taken from five experiments for each specification.

Table 1. Modeling results of cross-cutting process of non-defective pieces into blanks by means of software SAWing_lumber

The blanks length,m	It is necessary to saw out blanks, lm	The coefficient of specified yield blanks
1,2/0,8/0,2	200/200/200	0,85
1,2/0,8/0,4		0,76
1,2/0,8/0,6		0,74

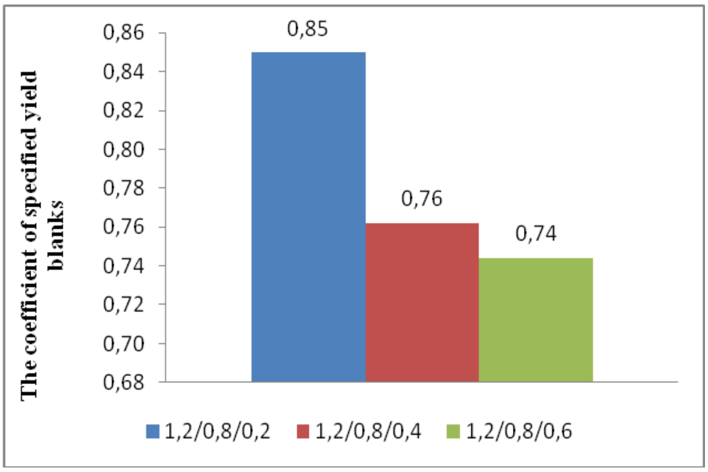


Fig.7. The dependence of the coefficient of specified yield blanks on their specifications

The results of the modeling (Table 1 and Fig. 7) show that with the increasing length of the shortest blank in the specification, the index value of specified output decreases. This is caused by the volume increase of raw materials due to the fact that the non-defective pieces, the lengths of which are less than the length of the shortest blank, are unsuitable for their cutting. These results confirm the adequacy of functioning of the developed software SAWing_lumber and appropriateness of its use for scientific and practical purposes. For the efficiency of software SAWing_lumber should make settings of FES [4, 5], and compare the results with actual results of cutting.

Conclusions:

1. A specialized software SAWing_lumber for simulation modeling process of lumber cross-cutting into blanks. Modeling results of dependency of specified output of blanks on their specifications were confirmed by the adequacy of its work.

2. The developed software is created without usage of expensive software that increases its value.

3. The software SAWing_lumber operates the data that can be obtained directly in the real cutting process of lumber on blanks, which indicates the possibility of its application in a real production environment of cutting.

4. For increase of the efficiency of software SAWing_lumber it is necessary to make FES settings and compare the results with actual results of cutting.

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УДК 674.093.6:674.061.2 ***Асист. Я.В. Мацишин; доц. В.О. Маєвський; студ. А.М. Дель Ріо – НЛТУ України; доц. С.І. Білик д-р техн. наук – КНУБА***

Спеціалізоване програмне забезпечення для моделювання процесу поперечного розкрою пиломатеріалів

Розроблено спеціалізоване програмне забезпечення “SAWing_lumber” яке моделює процес поперечного розкрою пиломатеріалів на заготовки керуючись ріненням нечіткої експертної системи стосовно вибору поточної схеми розкрою. Наведено діаграму класів, описано алгоритм роботи та правила користування інтерфейсом програмного забезпечення. За допомогою програмного забезпечення змодельовано процес поперечного розкрою пиломатеріалів на заготовки. Результати моделювання підтвердили адекватність та практичну цінність програмного забезпечення.

Ключові слова: програмне забезпечення, моделювання, пиломатеріал, розкрій, заготовка, бездефектна ділянка, схема розкрою, експертна система, нечітка логіка.

UDC 674.028.9. ***Competitor R.S. Marunych – UNFU***

A STUDY ON THE ISSUE OF ADHESIVE JOINTING DURABILITY AND THE WAYS OF THE DURABILITY PREDICTION

The paper deals with the analysis of glueing process, considers the adhesives that are used in woodworking industry. The problems associated with studying adhesive jointing durability have been examined. The main means and ways of enhancing the adhesive jointing durability are described.

Keywords: adhesive jointing, durability, adhesive, ageing process, stresses, operating conditions, prediction.

It is difficult to imagine the modern furniture making process without application of various kinds of adhesive. By way of glueing, one can obtain new forms of ware design; it is possible that different materials could be combined with wood thereby mitigating the effect of wood's natural defects. It should be remembered, however, that the woodwork item in the process of glueing must be considered as not a uniform body, but a complex structure consisting of different materials that have their own properties.

That is why the corresponding requirements are placed upon the woodwork item in terms of strength, reliability, and durability. Upgrading of the reliability and durability of furniture stock is an important task of the woodworking industry, while also being a significant scientific problem. It is well known that the durability of wood glued articles is strongly dependent on the quality of the adhesives used, glueing conditions, and the quality of the wood material. A variety of adhesives and glues are used for glueing wooden items: glutinous (bone and hide), casein, and synthetic adhesives, the last are being most widely used ones at the present state of the industry [1].

Synthetic adhesives offer a certain number of advantages over the other types of glues: they are water-resistant, fungi-resistant and make for obtaining a strong glue line. They come in various forms: solid, powder, liquid, and film (sheet). The adhesives can be dissolved in water, alcohol, emulsion [2]. The totality of operating experience of synthetic adhesives (over 80 years) shows that the glued articles give extended service as evidenced by many examples. Besides, the results from experimental investigations on the durability of wood joints glued with synthetic adhesives also point to their high degree of durability. However, the problem of glued wood durability is not still completely solved. Great difficulties emerge when generalizing the results of previous studies because there is not enough information about the adhesives being investigated, also the glueing techniques have not been adequately studied yet.

When analyzing the problem of durability, it is pertinent to define the meaning of the term "durability" as such. "Durability" is considered to mean the length of service time during which an adhesive jointing is capable of retaining the required strength, stability, and serve all necessary functions. As to the glue line, its durability is defined as the operating life under loading to the point of initial stage of destruction [3].

The study of wood adhesive jointing durability is impossible without knowledge of physical-and-mechanical, chemical properties of polymers, wood science, woodworking techniques, etc. although wood adhesive jointing is technologically simple, it is, however, rather a complex structure in terms of scientific analysis, One of the most cjmplicated tasks,when studying the adhesive jointing durability, is to find the way of evaluating the combined effect of internal stresses and the ageing process. The current approach to analyzing the mechanism of adhesive jointing failure under operating conditions involves discriminations between these two groups of factors: it is believed that, in some cases, the stability of adhesive jointing is determined by the process of ageing, at other times it is determined by internal stresses. In most cases, the laws of mechanics for polymers allow for integration of these two views to create the basis for common criteria for assessment of adhesive jointing properties. With knowledge of the fundamental tenets of the theory of strength, deformation, and mechanism of polymer failure, it is possible to gain an impression, with a high degree of accuracy, of how adhesive jointing behaves and varies over time under the action of external factors. The internal stresses and relaxation processes are of considerable importance, these are often the factors that determine the behavior of adhesive jointing during its operation. When assessing adhesive jointing durability, the effect of environmental factors such as temperature, moisture, atmospheric conditions, various kinds of radiation should by taken into account. The ageing of adhesive jointing can be caused by evaporation of the solvent, the plasticizer migration and various diffusion processes. The most contributing factors that deteriorate the properties of adhesive jointing during its service life are as follows: loads – static and dynamic; temperature and electro-magnetic fields; water, air, light; various microorganisms. The above factors may affect the adhesive jointing singly or together. In order to obtain a comprehensive idea of the adhesive jointing behavior during its service life, let consider the main methods of durability identification. The study of ageing processes is based on determining relationship between variation in mechanical strength values and duration of the experimental studies.

The study of adhesive jointing durability should also involve the notion of prediction. By prediction is meant foreseeing the degree of change in output characteristics of the adhesive jointing under certain conditions of prolonged service. The main methods of prediction can be divided into two groups: (1) the methods that do not take into consideration the action of external loads; (2) the methods involving prolonged loading. The methods of group 1 are not widely used since adhesive jointing is mainly operated under loads. The prediction for adhesive jointing that is not subjected to prolonged loading, is based on the studies involving considerable temperature and moisture differences that exceed the normal conditions of service by several times, which may eventually result in rapid loss of strength. The use of the results obtained by this method is not possible until they are correlated with the values obtained from natural ageing of adhesive jointing [4]. In predicting mechanical properties of adhesive jointing, which takes into account the action of loads, two methods (a method of computation and a physical method) are used. The method of computation allows the adhesive jointing durability to be predicted by way of estimation of the maximum stress in the glue line with regard for relaxation time, or without this, and then to compare it with the strength value obtained under conditions of standard investigation. From this standpoint, methods of computation are suitable for predicting the integrity of adhesive jointing. The physical method is based on the concepts of strength and durability of solid bodies with consideration for molecular structure of the objects under investigation. The most accessible subject for macroscopic inspection and the purpose of prediction is time – dependent strength of solid bodies based on the kinetic theory of strength. There are two kinds of prediction: approximate and accurate. The approximate prediction is made on the basis of comparison and correlation with the data for similar adhesive jointing constructions. The basis for such predictions is the application of coefficients by means of which the nature of relationship between the normal and speeded-up conditions of service is determined. The accurate prediction is impossible without knowledge of the rate of change in the adhesive jointing properties. In this case, the procedure of experimental investigation is based on the speeded-up process of ageing. The methods of approximate and accurate prediction make it possible to obtain necessary information which is relevant when creating adhesive jointing, introducing new glueing materials, developing new bonding techniques as well as introducing new methods of quality control for adhesive jointing. The methods of studying speeded-up ageing or ageing under standard conditions of service are the only way of determining adhesive jointing durability. A knowledge of methods of accurate prediction makes it possible not only to determine the durability of adhesive jointing, but also allows for taking a step forward: to control durability.

In the last few decades, radically new techniques have emerged, which allows carrying out diagnostics of constructions during the whole period of their service. Previously, designer's task was to create a construction that would have the greatest possible service life, while today they are trying to create a construction with controlled durability. This does not mean that the problem of enhancing durability is no longer topical. Resent approach to setting up this problem lies in the fact that one way of enhancing durability is how timely the damages are diagnosed. The problem of controlled durability can be considered from two points of view: ensuring trouble-free service for a certain length of time; setting up the time of performing maintenance work. The main causes of adhesive jointing may failure be as follows: formation of central crack that gradually grows and increases in size, which may lead to the adhesive damage; progressive accumulation of stresses that may result in formation of many microcracks, which, beginning with a certain point, may cause the adhesive to decompose with further breakage of the adhesive jointing as such [5].

Probable causes of defects and the probability of their impact on the durability can be divided into three groups: group 1 refers to the errors that arise when designing the constructions; group 2 is associated with the production process; group 3 is due to improper operating conditions. The factors of group 1 influence the rate of crack propagation whereas group 2 and 3 are associated with the factors causing the glue line defects. The dependence of defect formation probability on the design, technological and operating factors makes it possible to predict and prevent adhesive jointing failure. The problems in predicting should be solved step-by-step at the design stage: working out technological requirements that are to include a detailed list of operating conditions; the preparation of adhesive that is capable to meet the most part of the requirements; developing optimal glueing conditions; selection of means for controlling the materials and production process when training the technical personnel.

Once all probable problems are revealed and the ways of their timely solution are found, the probability of failure can be easily reduced to a minimum. Also, this will help reduce the probability of damage to glued constructions in case of accidental loading. The traditional methods of ensuring high durability include: proper design of the adhesive jointing; the jointing is to withstand heavy operating loads; high penetrating power and spreading of the adhesive; the use of the adhesives that are capable of restoring their original properties.

One way of ensuring high durability of adhesive jointing is strict observance of technological requirements at all, without exception, work stations. Everything, even small things, is of importance in this matter; all technological process operations are indiscriminately important in providing high quality adhesive jointing.

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УДК 674.028.9. *Здобувач Р.С. Марунич – НЛТУ України*

Аналіз питання довговічності та способи її прогнозування

Наведено аналіз процесу склеювання, клеїв що використовуються у деревообробці. Проаналізовано проблеми, що виникають при дослідженні довговічності. Приведено основні способи впливу на довговічність клейових з'єднань.

Ключові слова: клейове з'єднання, вологість, адгезія, довговічність, прогнозування довговічності, міцність з'єднань.

UDC 674.04

Competitor B.M. Myakush – UNFU

DEVELOPMENT OF THE CONDITIONS PARAMETERS OF GLUING PARQUET BOARDS WITH THERMOPLASTIC ADHESIVES

Presented in this work are the results of experimental study of gluing parquet board with thermoplastic polyvinylacetate adhesives (PVA). Gluing conditions parameters were developed for gluing three-layer parquet boards with polyvinylacetate adhesives.

Keywords: adhesive joint, parquet board, gluing conditions, polyvinylacetate adhesives, production process.

Among the main factors that affect the strength of glued wood structures is the type of adhesive used. In parquet manufacturing, urea-formaldehyde adhesives are commonly used for gluing. The main disadvantage of these adhesives are brittleness of the glue line, considerable shrinkage, low heat- and moisture-resistance [1, 2].

Obtaining environmentally-friendly parquet boards as well as wood adhesive jointing is of major importance today, this being the requirements for modern production process. It is possible to use polyvinylacetate-based thermoplastic adhesives instead of thermosetting urea-formaldehyde adhesives for gluing parquet boards. This was supported by investigations conducted at Ukrainian National Forestry University. According to the results of the investigations, these types of adhesive exhibit good adhesion properties as to wood, they form elastic glue line, they are nontoxic and can bear loads of D3 and D4 classes according to European standard DIN [5]

The use of these types of adhesive would make it possible to produce parquet boards on an environmentally sound basis as the adhesives meet the existing sanitary and technical standards; they can ensure low water absorption of the end product, the parquet boards are easy to machine after gluing and they will also have good heat and sound-insulation properties etc. To study the effect of thermoplastic PVA adhesives on the strength, a three-layer parquet board was used as a test specimen while gluing was done with thermoplastic PVA adhesives of D4 load class that have been formulated at Ukrainian National Forestry University. The direction of grain of each layer of the three-layer parquet board is at an angle of 90º to the grain of each other layers. The primary layer is the upper one which is called thin parquetry. It was made of oak wood. The thickness of the layer is 6 mm, its quality meeting standard GOST 862.3-86 [5].

The core of the parquet board was made of softwoods species – pine wood. For this purpose, strips of cross-section 26x9mm were fabricated. The allowable variation of the strips width is up to 1mm while the gap between the strips edges does not exceed 3mm. The selection of the stock was done according to GOST 2140, in so doing the size of the knots was determined by the smallest diameter. The strips of the core were laid with the grain direction oriented mutually perpendicularly to the upper and bottom layers. The bottom layer of the parquet board was made of plywood 44 mm in thickness.

The test specimens of parquet boards are 250 mm in length, 95 mm in width, and 18 mm in thickness [3]. The wood species of the layers: the upper (thin parquetry) –oak wood 5 mm thick; the core − pine wood strips measuring 250x26x9 mm; the bottom layer-plywood 4 mm thick. The moisture content of the parquet boards was measured by means of moisture meter according to GOST 16588.

The adhesive was evenly applied to the face surface. The adhesive spread was controlled by means of electronic Pocket scale MH-200 200g/0.01g scales (with an accuracy of 0.01 g). The adhesive having been applied, a parquet block was assembled.

Once assembled, the parquet block was loaded into single-daylight press where the process of gluing took place. The pressing was followed by the parquet block conditioning for 120 hours, after that the parquet blocks were cut into test specimens of the following size: length – 250 mm, wigth – 95 mm, thickness – 18 mm, the test specimens were prepared according to the procedure of strength testing by the GOST 862.3-86 standard. By means of circular saw, a “tearing off “ spot of 48 mm wide was cut out on the face surface. On the back side of the specimen, the layout of holes was made first, then three blind holes of diameter 16mm were drilled on the upright drilling machine through the thickness of the plywood and the core of the parquet board abutting on the oak lamella. The holes and kerfs arrangement is shown in Fig. 1.

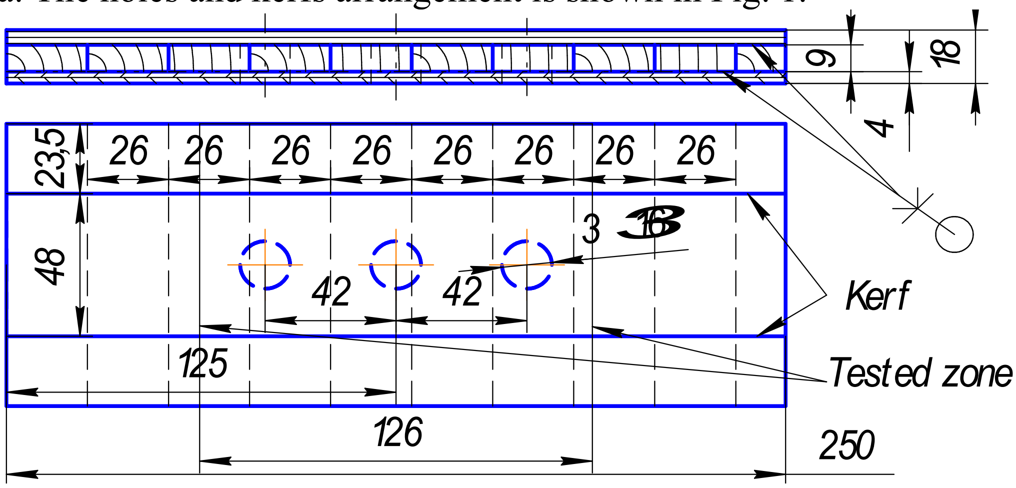

Fig. 1. Specimen for testing the parquet board strength: *1 – kerf; 2 – tested zone*

The test was conducted on the versatile testing machine according to GOST 28840, the measurement error being no more that 50 N. To break the specimens, a device, as shown in Fig. 2, was used.

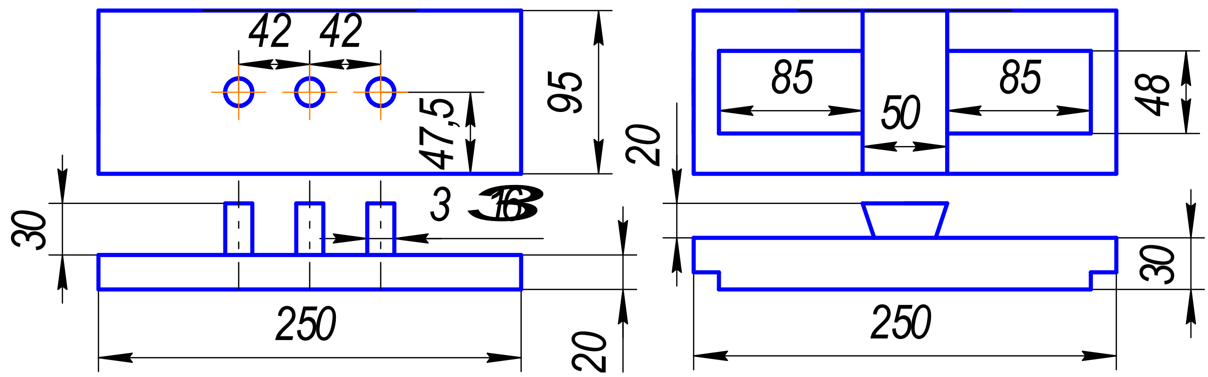

Fig. 2. Device for determining parquet board strength
1 – fork-like rods for destructing specimen

In the course of experiments, three strength-affecting factors were studied: adhesive spread (X_1) ranging from 120 to 160 g/m²; press time (X_2) ranging from 40 to 60 min, and press pressure (X_3) ranging from 100 to 160 kg/cm². These factors variations were chosen based on the previous experimental studies. The specimens were numbered according to the experiment number. The results of the investigations are shown in Table 1.

Table 1. The results of investigations

№ experiment, n_o	Ultimate strength of par quet board adhesive joint, MPa			
	observation, n_o			
1	0.337	0.415	0.311	0.259
2	0.458	0.486	0.631	0.778
3	0.668	0.707	0.478	0.826
4	0.932	0.850	0.657	0.770
5	0.307	0.227	0.441	0.359
6	0.556	0.586	0.497	0.450
7	0.458	0.406	0.378	0.342
8	0.473	0.359	0.562	0.482
9	0.562	0.679	0.620	0.616
10	0.694	0.703	0.700	0.707
11	0.560	0.612	0.592	0.582
12	0.614	0.668	0.664	0.720
13	0.649	0.627	0.670	0.644
14	0.649	0.631	0.675	0.651

In order to construct a regression model, B-plan was used in the form of the second order polynom which is written by the formula

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x^2 + \sum_{i \le j}^{k} b_{ij} x_i x_j \,,$$

where: y – response value; b – regression coefficient; x – independent variable.

In the selected plan of the experiment, each factor varies at three levels: upper (+), lower (–), and datum (0).

The statistical processing of the experimental results is done according to the procedure [4], the following regression equation was obtained in coded values of the factors:

$$y=0.283+0.029x1+0.026x2-0.027x3-0.020x1^2-0.034x2^2-0.034x2^2-0.024x3^2-$$
$$-0.012x1\ x2-0.006x1\ x3-0.027x2\ x3$$

The optimization was done by means of computer, and the following optimum technological parameters of gluing condition were obtained: adhesive spread Q=159 g/m²; press time T=57 min; press pressure P=145 kgf/cm². The analysis of the optimum conditions parameters showed that the bonding strength tends to increase with increase in adhesive spread. The influence of press time on the parquet board strength does not vary directly with increasing time, that is, gradual increase in the press time up to the mean value results in increased strength of the parquet board while its further increase up to the maximum value results in somewhat decreased strength of the parquet board, also, gradual increase in pres pressure up to the mean value leads to increased strength of the parquet board while its further increase up to the maximum value results in somewhat decreased strength of the parquet board.

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УДК 674.04 ***Здобувач Б.М. М'якуш – НЛТУ України***

Розроблення режимних параметрів склеювання паркетної дошки термопластичними клеями

Наведено результати експериментальних досліджень склеювання паркетної дошки термопластичними полівінілацетатними клеями. Розроблено режимні параметри склеювання тришарової паркетної дошки термопластичними полівінілацетатними клеями.
Ключові слова: клейове з'єднання, паркетна дошка, режимні параметри, полівінілацетатні клеї, технологічний процес.

UDC 07.01 ***Assoc. prof. S.P. Mygal – UNFU***

THE THEORETICAL AND METHODOLOGICAL BASIS OF FURNITURE DESIGN

The article examines the problem of the formation of methodological basis and strategies of furniture design in social system environment. The basic principles, tools and patterns of furniture design in human environment have been determined.
Keywords: design, furniture, social system environment, principles, means and patterns of design.

Problem formulation: The advancement of special subject environment designing and of design culture in the conditions of the social sphere stage of constant human development, of changes in ideological orientation, of global urbanization, and discovery of new areas of knowledge in natural sciences have brought the revision of civilization strategies and change of values.

A person has become the social personality which is able to act systematically and purposefully, to form the objective world by changing the environment, his/her own life and essence. A person has already become, in his/her development, less dependent on biotic factors or need to adapt to variable environmental conditions. Both mass media sphere and social sphere has become one common environment for the existence of mankind. Design is now viewed in the broad socio-cultural context when integral socio-cultural situations are being formed through harmonic structuring of objective and processual aspects of the system "man–environment" as well as through programming such systems according to the principles of constant development.

There appear a number of fundamentally new tasks and functions which require the theoretical and methodological principles of design to be significantly updated. There is an actual need to comprehend new social, ecological, economic, technical and technological conditions and to form the theoretical and methodological basis of design.

The aim of the article is to determine the theoretical and methodological foundations of furniture design, to identify the principles, methods and patterns of their formation.

Nowadays design is a theoretical and applied discipline which deals with forming a balanced spatial object environment, regulating human life activities, forming meaningful and structural objects of material and spiritual culture. It is treated as an aim of scientific research and designing within the system "man–object–environment." In the philosophical meaning of the word, design is an integral system of professional thinking that can create ideas in order to regulate human life as much as possible according to the needs, ethical and aesthetic standards of the given era, as well as of the given social and cultural center.

The nature of design is changing with the development of communication technologies and it turns into the art of man's self-expression. The possibility of unrestricted self-expression reveals limitless horizons for designers.

Spatial object environment is now viewed as a structural component of the multidisciplinary and multidimensional space of the geosocial system which is a multiplicity of lesser self-organized systems that endure periods of stability and leaplike transitions into a different state, while the Universe is viewed as an unpredictable system which is constantly changing in its development. This is the impetus which has led to emergence of a new furniture design paradigm in the formation of spatial object environment.

Human activities environment is an integral structure of both internal and external space, a complex system, both naturally and artificially created, where the synergy of physical, chemical and biological effects is taking place.

To see the social space continuum as a self-organized planetary system with all its components, complex relationships and interferences, and to think design as anthropocentric is to open new opportunities for the formation of the social system environment.

The achievements of urban synergetics, physics, chemistry, molecular biology, informational and digital technologies, and of nanotechnology expand the study of human evolution in its self-organization and harmonious development of the evolution, when we can penetrate to the smallest structures of a living organism, its genetic memory/ Due to emergence of new technologies and exploration of new forms of energy, due to exponential development of computer science and other advanced technologies for designing and shaping the environment man has become less dependent on biotic factors, or the need to adapt to the changing environmental conditions.

Man is now able to modify the structure and functions of natural ecosystems, and to create artificial ecosystems and geo-social systems while forming a holistic human environment. The theoretical basis of furniture design, like that of the environment design in general, is defined by the ideologies of environmentalism, of geo-social system engineering, of social, cultural branches of science and engineering, including urban architecture, of the methodologies of system analysis and synthesis of quantitative and qualitative morphological, praxeological tectonic and axiological indices and characteristics. It is clear that a set of requirements to object design and environment design, and also necessary concepts and strategies are to be taken into consideration [1-7].

Comprehending space as a multi-vectorial planetary continuum, considering the open and nonlinear progress of evolution, understanding social sphere as a self-organized system, as a creative and heuristic potential of the synergistic outlook and digital technologies, analyzing the ways of formation of the synergic paradigm of environment design, and of the systems of new reality, we may outline the principles, means and main patterns of design (Table 1).

Table 1. Principles, means and patterns of design

Principles	Means	Patterns
1	2	3
Anthropo-centrism	Exploring of the issue and its context. Target installation. Social, anthropological and ecological aspect of design. Life conditions and the process of human interaction with the environment. Tactile-kinaesthetic and tactile sensations.	The central position of man in the system of design and consumption. Meeting the material and spiritual needs of individuals
Social system environment	Laws of environmentology, anthropic and natural creative principles of synergetics. Structural and functional analysis. Diachrony and pseudo-hierarchy of systems. Holistic and synergetic paradigm of worldview.	Structuring the problems. The synergetic paradigm of design. Formation of the concept and algorythm of designing activity.
Innova-tiveness	Non-typical thinking. Heuristic methods of analysis and synthesis, means of anticipation, ideas of nonlinear theory, methods of digital design, art design.	Generation of new ideas, unique objects and systems of new reality.
Individual-ism	Ontogenesis. Ideas of individualism, evolutionary development and originality of the processes taking place in the system.	New forms, structures and approaches to organizing space and processes of human activities.
Variability	Parametric design. Solving of the problem by means of algorithmic changes which are generated by software.	Correlation of changes by all elements of the system, object and environment.
Non-stop experi-menting	Synthesis of virtual and real heuristics	Bilateral integration of the system: a model, simulation, the reality.
Coordina-tion	Coherent coordination. Interaction between dimensions of space and time. Creative collaboration with experts of related disciplines at all stages of the life cycle of the system	Perfect understanding of the essence and progress of the work. Project analysis. Conceptual model formed.
Purpose-fulness	Synergistic direction and coordination of internal processes, structures and resources.	Self-organizing systems. A sufficient diversity of human needs, meeting the conditions of space and harmonious development.
Ad hoc approach	Contextualism and complementarily of the system. Future consumers as participants in designing.	Optimizing human life activities
Genesis of structure	System-analysis research. Planning and organization of space. Using quantitative and qualitative epistemological, reflex logical and axiological characteristics of objects and systems.	Ranking factors, functions and conditions of space. Structural and functional analysis. Steps of design and their analysis. Compositional interpretation of the structure.
Morpho-genesis	Means of formation of spatial and functional structures and the environment	The establishment and development of material forms and structures relevant to the laws and values of evolution.
Tectogene-sis	Spatiotemporal organization of forms and structures	Construction of new tectonic forms and structures
Integrity	Synergetic and systemic principles. Synthesis of science, technology, art, architecture and design	Interaction and interference of the material and the spiritual, the object and the subject, living and inert matter, science, art and design
Unity	Compatible examination of the system both as a whole, and as a set of components, their internal and external links and system-making relationships	Providing structural and functional community, integrity of the systemic object, as well as unity of its pragmatic consumption and aesthetic evaluation
Fractality	Using fractal algorithms. Shaping the object on the principle of its self-identity and invariance	Diversity, unpredictability, charm and invariance by scale. Dynamic development of structures made up of similar forms.
Variability	Choosing alternatives or their combination.	Providing the necessary diversity, alternatives and effective strategies of development.

Optimality	Improving the quality and economy of system resources	Optimizing the process of functioning in certain spacio-temporal limits
Symbolism	The visual language. Semiotic foundations of signs and sign systems. The system of visual characteristics of an object.	Symbolic and communicational links between an object, man, and space.
Dynamism	Technologies of parametric design. Evolutionary transformation of self-organization properties, means of transformation and mobility	The ability to improve and develop the system. Orientation at or adaptation of the object or system to the changing needs for their production and consumption.
Adaptability	Continuity and complementarily. Principles of static and dynamic adaptation	Eliminating conflict between constant and variable human needs and unchangeable environmental characteristics
Harmony	Means and techniques of compositional shaping and synergetic harmonization. Harmonious arrangement of the human dimension, internal system processes and the influences from outside	The balance and harmony of the artificial human environment. The relationship between harmony and self-organization
Economy	Macroeconomic and microeconomic aspects of the designed product in the light of latest theories	The economic feasibility of designed product

The above-mentioned principles, means and patterns of design correspond to each other. They are directly linked to designing activities and are suitable for shaping the designing policy, also the strategic theoretic and practical principles of the design of objects and of spatial object environment.

Conclusions. Defining of scientific and methodological foundations of design will help to delineate the designing policy, the strategic and practical principles of design. There are grounds to suggest that their foundation would provide for qualitative changes in the methodology and technique of both furniture design and that of the human activities environment. Further research is aimed at improving the scientific and methodological foundations of design.

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УДК 7.01 ***Доц. С.П. Мигаль, канд. арх. - НЛТУ України***

Науково-методологічні основи дизайну меблів

Розглянута проблема формування методологічних основ і проектних стратегій дизайну меблів соціосистемного середовища. Визначені основні принципи, засоби і закономірності дизайну меблів середовища життєдіяльності людини.

Ключові слова: дизайн, меблі, соціосистемне середовище, принципи, засоби і закономірності дизайну.

UDC 674.028.9 *Assist. V.R. Solonynka – UNFU; prof. S.F. Gavenko – Ukrainian Academy of Printing; prof. V.M. Atamanyuk – Lviv Polytechnic National University*

THE INFLUENCE OF CHEMICAL COMPOSITION OF WOOD ON THE STRENGTH OF JOINTS FORMED BY POLYVINYL-ACETATE ADHESIVES

The analysis of the influence of chemical components of wood on the joints strength formed by polyvinyl-acetate adhesives is provided. To study the effect of chemical composition we received test results for shear along the fibers of massive and laminated ash wood, as well as samples of modified vacuum-conductive thermal processing.

Keywords: Adhesive compositions, dispersion, shear strength along the fibers, heat treatment, cellulose, hemicellulose, lignin and extractive substances.

Problem statement. While manufacturing wood products the formation of strong and long-lasting joints is an important process. So, it is necessary to choose adhesive compositions which would fully meet technological, operational, environmental and economic requirements that are directly dependent on the purpose, structure and other characteristics of the product in which they are applied. Besides, if do not follow operational conditions of the process and violate the requirements for preparation of gluing surfaces, bonding even with the help of correctly selected glues may give unsatisfactory results.

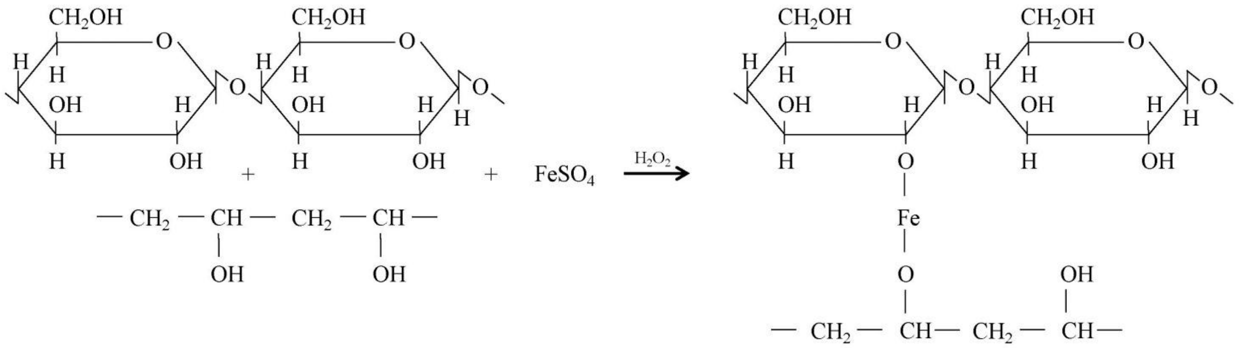
Joints formation of two or more homogeneous or inhomogeneous materials in a single system by using adhesive compositions is conducted on condition that they follow the processes that contribute to the formation of joints inside the adhesive. Thereby, a cohesive strength can be formed; adequate adhesion strength and the glued surfaces can be provided. In some cases, while forming joints in the adhesive layer the processes of self-adhesion are observed – the adhesion of molecules of homogeneous materials without undergoing chemical reactions. The most difficult part of the above mentioned processes is to describe the mechanisms of adhesive joints. The theory of adhesion outlined in the literature is used to describe them [2, 4, 6].

It should be mentioned that much more attention is paid to the study of formation of adhesive and cohesive joints while applying glues based on thermosetting polymers than to the description of mechanisms, which are used for bonding wood thermoplastic water-dispersion systems. Though, some authors partially describe the joints formation processes conducted with the help of water-dispersion adhesives, but little attention is paid to the properties of gluing materials [5, 7].

The aim of the present paper is to describe the influence of the chemical composition of wood substrate on the adhesion strength formed by a modified polyvinyl-acetate dispersion (PVA dispersion-VS) joints. For the purpose of obtaining samples with different chemical composition, part of ash wood aimed at producing samples was processed in its unrestrained condition, and another part was previously exposed to vacuum-conductive heat treatment.

The main information. Most of wood species consist of organic compoundsto the extent of 99% or more. The main compounds are cellulose, hemicelluloses, lignin and extractive substances (soluble in water or the air) [1, 8]. Among above mentioned compounds one of the most important for the formation of strong adhesive bond between PVA dispersion-VS and wood is cellulose. This polysaccharide is reactive and its content exceeds any other components.

Considering the fact that the sulphate of iron (II) and hydrogen peroxide enter into the modified PVA dispersion, so during the formation of joints at the interface of wood, substrate-glue will undergo the reaction of iron sulfate (II) not only with polyvinyl alcohol, which is also included in the mixture, but with the reacting centers of cellulose, which are located in the boundary layer for the formation of complex structures that will improve the adhesive strength of the system:



Other compounds that enter into the wood can be relatively divided into two groups: the first – those which contain hydroxyl groups (-OH) and are able to form hydrogen bonds, the second are extractive and water-insoluble components.

The first group includes lignin and hemicelluloses (pentosans and hexosans). These substances do not enter into the direct chemical reactions with the components of polyvinyl-acetate dispersions, but they are able to form hydrogen bonds with molecules of polyvinyl alcohol. The energy of these bonds is much smaller than the energy of covalent or ionic bonds, but a large number of contact points provides significant cumulative effect over the entire area. Besides, it is important to consider the cellulose because it has -OH groups and it means that such cellulose will also help to increase the strength of adhesive joints due to the formation of hydrogen bonds.

Special attention should be paid to arabinogalactan. It is the only water-soluble polysaccharide of wood which relates to a group of hexosans. Highly branched structure and dissolution in water are its characteristic features. Made solutions have sticky properties that enable to use them as adhesives [8]. Since the water is dispersion medium in the glue PVA dispersion-VS, it can be assumed that during the contact with it, parts, available for interaction, may partially diffuse into the adhesive joint. The bonding remains there after the water removing and process completion, thus increasing the strength of compounds formed by coordination or hydrogen bonding and also mechanical blocking of macromolecules by other adhesive layer components. In order to check the influence of wood chemical constituents on the adhesive strength of joints formed by modified PVA dispersion, a certain research of bonding and ash wood heat treatment was conducted. The process of wood processing is being conducted in the laboratory with the help of equipment for testing and according to the method described in the study [3] that meets the current regulations. An ambient temperature of 220 ^{o}C and duration of exposure 4 h. were chosen for conducting the heat treatment.

The shape and size of the samples and also the method of testing the strength of adhesive joints for shearing along the fibers meet the requirements of GOST 15613.1-84. The joints formation is being conducted under the following operating conditions: press pressure – 0.6 MPa, glue spread – 160 g/m2, open holding duration – 8 min, pressing duration – 60 min. The received results of testing adhesive joints of ash wood, which is not exposed to heat treatment is much better than the results received during the destruction of adhesive joints of processed wood. The data can be seen from the diagram in Fig. 1. However, it should be mentioned that as a result of exposure to high temperatures of wood, its physical and mechanical properties change. It leads to a decrease in shear strength along the fibers. Therefore, the results analysis should be based on the comparison of test results of laminated and solid wood samples from heat-treated and normal ash wood.

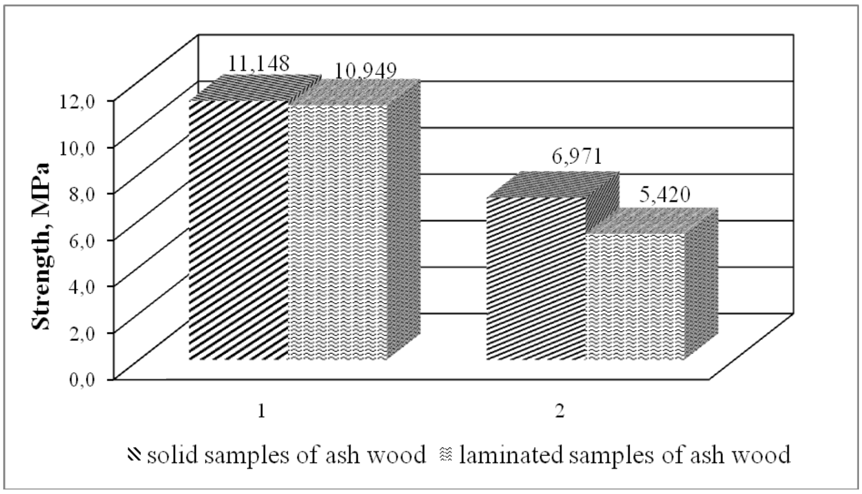


Fig.1. The shear strength of samples along the fibers:
1 – the test results of solid and laminated ash wood samples,
2 – the test results of solid and laminated samples from heat-treated ash wood

From received dependences it is seen that the shear strength along the fibers of laminated and solid samples of ash wood is almost of the same level. Besides, mixed type of fracture mainly in wood is observed while testing laminated pieces.

While conducting the research on heat-treated wood, the difference of the results between the solid and laminated samples is much higher and is 22%. It can be explained by the fact that while treating ash wood at a temperature of 220 ^{o}C the processes of thermal deterioration occurs. The rate of decomposition of lignin and hemicellulose is high under such conditions which completely eliminates or drastically decreases their content in glued layers of wood. The only polysaccharide, the quantitative content of which does not change, is cellulose, because it is more thermal-resistant and is subjected to slight changes in the chemical structure of the constituent parts and a slight decrease in the degree of polymerization [1, 8]. The disintegration of a big part of complex compounds leads not only to a decrease in bonding strength, but also influences the process of wetting the surface while applying the composition PVA dispersion-VS as compared to similar solid samples. Since water is the dispersive medium in a modified dispersion and the large number of hydroxyl groups in the chemicals that form the basis of wood material contributed to its proper wetting, so, it is natural that the decrease of these compounds leads to the deterioration process.

Conclusions. It has been found that the chemical composition of wood influences the strength of adhesive joint, because the difference in the shear strength along the fibers of laminated and solid samples of the heat-treated ash wood is 22 % (in the worse case for laminated wood) while the strength of similar samples from unprocessed ash wood is almost identical (the difference is less than 2 %). Besides, while testing samples of laminated ash wood the type of distortion in wood was mixed and the destruction of similar models, but with heat-treated wood, was in glue that indicates a change in the formation of adhesive bond.

Thus, it can be concluded that the chemical constituents of wood are important in the formation of strong adhesive joints compositions based on PVA dispersion.

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УДК 674.028.9 ***Асист. В.Р. Солонинка - НЛТУ України; проф. С.Ф. Гавенко, д-р техн. наук – УАД; проф. В.М. Атаманюк, д-р техн. наук – НУ «Львівська політехніка»***

Вплив хімічного складу деревини на міцність з'єднань, утворених полівінілацетатними клеями

Наведено аналіз впливу хімічних компонентів деревини на міцність утворюваних полівінілацетатними клеями з'єднань. Показані результати випробувань на сколювання вздовж волокон масивної і клеєної деревини ясеня, а також взірців модифікованих вакуумно-кондуктивним термічним обробленням з метою зміни їх хімічного складу.

Ключові слова: клейова композиція, дисперсія, міцність на сколювання вздовж волокон, термообробка, целюлоза, геміцелюлоза, лігнін, екстрактивні речовини.

UDC 674.028.9 ***Assist. V.R. Solonynka – UNFU***

THE RESEARCH OF THE STABILITY OF ADHESIVE JOINTS OF HARD-WOODED SPECIES (OAK WOOD), FORMED BY MODIFIED POLYVINYL-ACETATE (PVA) COMPOSITION, TOWARDS THE INFLUENCE OF WATER AND HIGH TEMPERATURES

The results of the research of adhesive joint strength changes of oak wood formed by adhesives on the basis of PVA dispersion of domestic and foreign production under the influence of cyclic temperature and humidity testing.

Keywords: adhesive composition, dispersion, modifying additives, ultimate split strength of wood along the fibers.

Problem statement. Today it is difficult to imagine furniture, carpentry and other products of woodworking industry, in which adhesive materials are not used. In fact, owing to their application we can provide savings of raw materials, facilitate technical process, and change the physical and mechanical, operational data of gluing materials.

Along with expanding the use of adhesives, the requirements change. First of all, adhesive compositions should meet operational and technological requirements as well as be available from an economic point of view. Besides, more attention is given to environmental requirements, which is very important for the manufacture of products for residential, office and other premises where a person spends most of his/her life. The existing environmental regulations currently meet water dispersion and water-soluble thermoplastic or thermosetting compositions and there is also part of reactive adhesives without solvents with dry weight that is close to 100 %. In particular the compositions based on polyvinylacetate dispersion belong to such adhesives. However, a significant problem is that the domestic industry mainly produces adhesives based on PVA dispersion with low resistance to the influence of humidity, water, and high temperatures [5, 6-12].

Consequently, the purpose of the study was to examine the influence of modifying additives on the stability of joints based on PVA dispersion of domestic industry towards the influence of temperature and humidity load.

Materials and methods of research. The shape and size of the samples and the method of testing the strength of adhesive joints along the fibers were selected according to GOST 15613.1-84 [2]. The experimental study of the influence of temperature and humidity loads were conducted according to GOST 17580-82 [4]. However, the very standard designed for thermosetting adhesives is too hard to be followed while testing thermoplastic compositions, so, only five cycles of testing were used for the research. It was enough to see the effect of the modification, as joints formed mainly from one-component polyvinylacetate adhesives are being destroyed after 3...5th cycle of temperature and humidity loads.

In order to perform the research, oak bars 25 mm thick were used, which were exposed to planing to thickness of 20 mm. The following brands for adhesive compositions were used: PVA dispersion-40P, PVA dispersion-51P, 53P-PVA dispersion and BONIDUR W D3 by Bochem. In order to improve the operational characteristics of the composition PVA dispersion-51P, the polyvinyl alcohol and modifying additives are added to it: hydrogen peroxide (H2O2) and ferrous sulfate (FeSO4).

The formation of joints was conducted under the following operating conditions of gluing process: pressing pressure – 0.6 MPa, glue spread – 160 g/m2, open holding duration – 8 min., pressing duration – 40 min. The research was conducted by using laboratory equipment and production equipment in accordance with current standards.

The results of research. In order to determine the stability of adhesive joints of oak wood the pre-testing procedure of samples formed by PVA dispersion-40P and 53P-PVA dispersion was conducted. The second composition is being exhibited by manufacturer that meets European standards EN 204, by class of water resistance D3 (for forming joints, which will be operated in indoors premises where they could be subjected to short-term influence of water and (or) long-term influence of high humidity) [3]. The results are shown in Table 1.

Table 1.The results of temperature and humidity testing of oak wood joints based on PVA dispersion

№	Type of glue	The split strength of wood along the fibers after appropriate test cycle, MPa			
		Control samples	1	3	5
1	PVA dispersion-40P	10,95	0,92	0	0
2	PVA dispersion-40P	11,3	3,2	0,48	0,06

Fig. 1 shows a graphical interpretation of strength changes of load cycles. It is seen from graphic dependences that after the first test cycle the split strength along the fibers for oak wood joints formed by PVA dispersion-40P is 0.92 MPa, which corresponds to 8.14 % of the initial strength, and after the third cycle the complete destruction of the researched materials occurs. Somewhat better manifested themselves joints formed by PVA dispersion-53P. After the first test cycle split strength is 3.2 MPa (28.6 % of the original), but after the fifth – 0.06 MPa. However, these figures are unsatisfactory, and such joints can be operated under the conditions of exposure to high humidity (relative humidity in the environment that exceeds the rate of normal conditions to 10 percent or more) or direct contact with water.

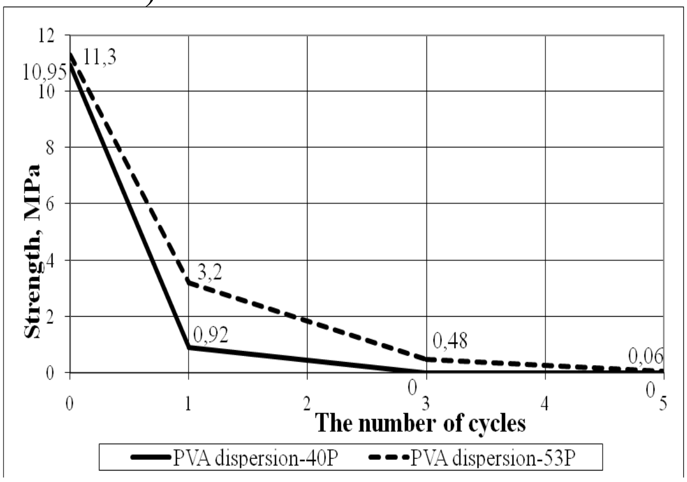
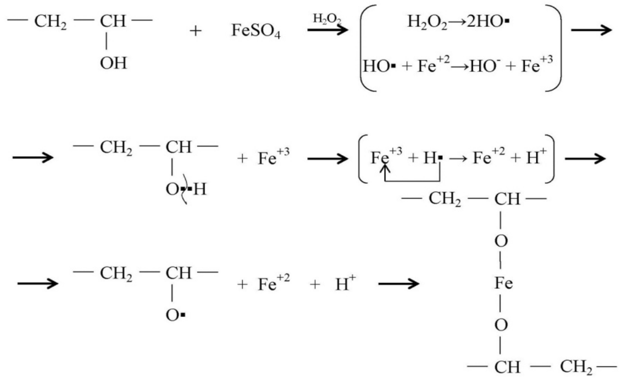


Fig.1. The dependence of the strength of oak wood glued with polyvinyl- acetate dispersions of domestic production on the number of cycles of temperature and humidity testing

The obtained results could be explained in the following way. Low water resistance of testing samples jointed with the presence of adhesive composition of an emulsifier – polyvinyl alcohol, which is a hydrophobic substance. Unsatisfactory thermal resistance connected not only with the properties of the emulsifier, but also with low thermal resistance of the polymer base (the softening begins at 40 ° C, and at 65-70 °C polyvinyl-acetate becomes viscous-flow state) [1].

The 51P-PVA dispersion produced by "Omega" is selected for the basis of modification. The characteristics of dispersion are slightly inferior to PVA dispersion-53P, but it is cheaper. Aiming at improvement of its operational characteristics, among which water, humidity and thermal resistance take the central place, it was offered to add to dispersion the ferrous sulfate (II) and hydrogen peroxide. The addition of these compounds aimed primarily at their interaction with emulsifier – polyvinyl alcohol. In order to increase the number of reaction centers, a small amount of free polyvinyl alcohol in form of water solution is additionally added to the mixture.

As a result of the reaction between polyvinyl alcohol and sulfate of iron (II) by the presence of the initiator in the formation of adhesive joint, the products with liquid structure are formed that results in improvement of operational characteristics and as a consequence – the formation of joint resistance to water:



For examination of the modification influence, oak wood joints formed by a new composition were tested, which we denote by abbreviations PVA dispersion-VS. The results are provided in Table 2. In order to compare the results with existing adhesives of European manufacturers, the samples with compositions by Bochem of class of water resistance D3 according to the standard of EN204 were produced for the check studies.

Table 2.The results of temperature and humidity testing of oak wood jointsbased on modifiedPVA dispersion

№	Type of glue	The split strength of wood along the fibers after appropriate test cycle, MPa			
		Control samples	1	3	5
1	PVA dispersion-VS	10,74	7,03	5,08	4,43
2	BONIDUR WD3	10,91	8,09	6,03	5,49

During the analysis of graphical characteristics, constructed according to Table 2 and provided in Fig. 2, it is seen that even the modified composition is slightly inferior to the stability of the glue BONIDUR W, but if to calculate the percentage of residual strength after the fifth cycle, it will account for 42 % of the initial values.

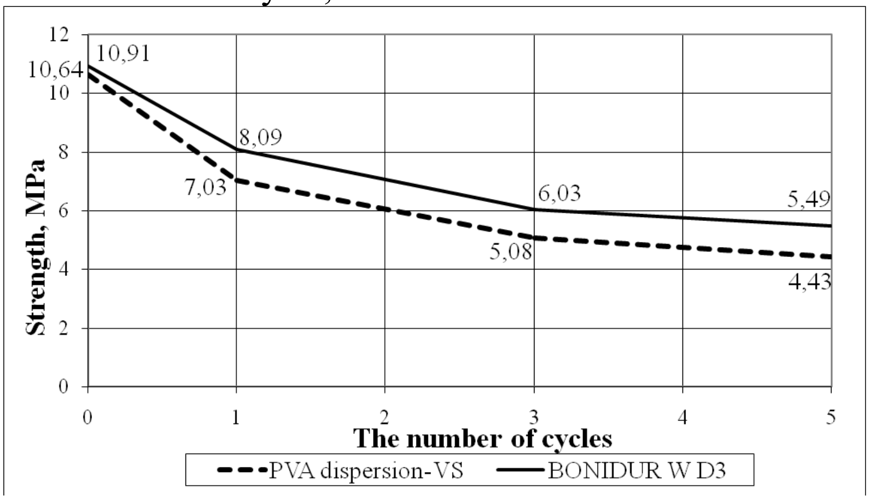


Fig. 2. The dependence of the strength of oak wood glued with the help of modified PVA dispersion-51P and BONIDUR W of the number of cycles of temperature and humidity test-

However, in order to see the modification influence, it is necessary to compare the test results of adhesive joints formed by PVA dispersion-VS with the results obtained when testing samples formed by PVA dispersion-40P and PVA dispersion-53P.

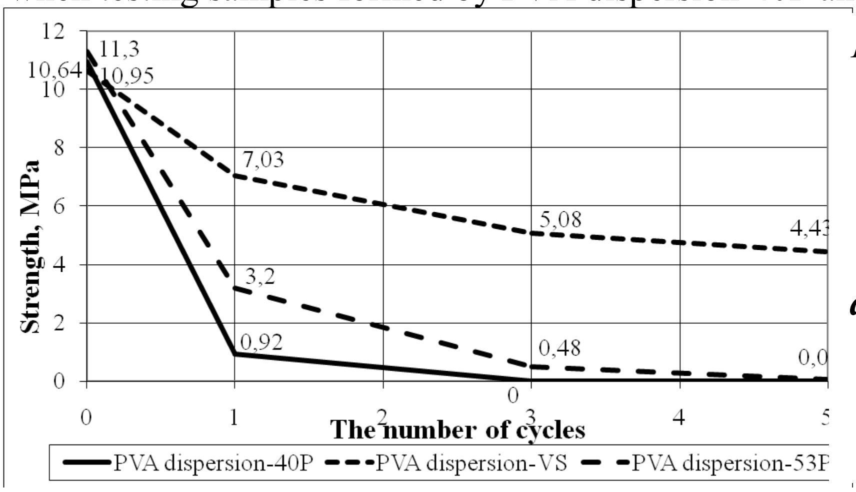


Fig.3. The dependence of the strength of oak wood glued with the help of modified and unmodified polyvinylacetate dispersions of domestic production of the number of cycles of temperature and humidity testing

From diagrams (Fig. 3) it is seen that the initial strength of the samples is rather smaller (10.64 MPa against 11.3 MPa and 10.95 in PVA dispersion-53P and 40P-PVA dispersion, respectively). Such difference can be explained by the fact that modifying additives occupy part of the contact areas of the polymer base (PVA) with wood, which leads to a slight decrease in strength. However, after the first test cycle the positive effect of modifying additives can be observed. The samples strength formed by PVA dispersion-VS is 7,03MPa, while joints from PVA dispersion-40P are almost destroyed by minimum external force. Consequently, none of the domestic compositions withstand the five cycles of testing, except the modified one (strength of 0.06 MPa for samples formed by PVA dispersion-53P is unacceptable when used, as such joints could be broken even by slight contact with the product).

Conclusions. It is observed that in order to provide the stability of adhesive joints of wood on the basis of PVA dispersion of domestic production, it should be modified by metal salts with the addition of the reaction initiators to the mixture. In this case, the complex of sulfate iron (II) and hydrogen peroxide was chosen. In order to ensure the best indicators of water resistance it is also necessary to add polyvinyl alcohol to the mixture, because it increases the number of reaction centers. It is due to the fact that adding of modifiers is primarily focused on their interactions with additional components of polyvinyl-acetate dispersions, among which isthe emulsifier– polyvinyl alcohol. The results shows that additional modification of polyvinyl-acetated is persions of domestic production forms a composition that can compete with common adhesives of European manufacturers by the class of water resistance D3, as a product that has low cost of production and good operating characteristics.

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УДК 674.028.9
Асист. В.Р. Солонинка - НЛТУ України

Дослідження стійкості клейових з'єднань твердолистяної породи (деревини дуба), сформованих модифікованою полівінілацетатною композицією, до впливу води і підвищених температур

Наведено результати досліджень зміни міцності з'єднань деревини дуба сформованих клеями на основі ПВА дисперсії вітчизняного і закордонного виробництва під впливом циклічних температуро-вологісних випробувань.

Ключові слова: клейова композиція, дисперсія, модифікуючі добавки, межа міцності при сколюванні вздовж волокон.

UDC 681.3.06:674.047 *Prof. Ya.I. Sokolovskyy, assist. I.B. Boretska, eng. P.I. Rozhak – UNFU*

DESIGN AND RESEARCH INFORMATION TECHNOLOGIES OF LUMBER DRYING KILNS BY MEANS OF SOLIDWORKS API AND COSMOSFLOWORKS

The system of computer-aided design SolidWorks 2011 has been used for the solid state modeling of a lumber drying kiln and the creation of three-dimensional models of its components. On the basis of SolidWorks API the program-oriented complex “Wood v.1.0” has been developed using the compiler Microsoft Visual studio 2010 which enables to research the chamber parameters, as well as control the geometry of the lumber drying kiln and stack. The thermal calculation and the analysis of physical steams in a lumber drying kiln have been done using design information technologies COSMOSFLOWORKS.

Keywords: CAD, SolidWorks, SolidWorks API, COSMOSFloWorks, model, lumber drying kiln, drying process, temperature.

Introduction. Design information technologies are introduced into all of the spheres of practical activities. They are a necessary tool for the design and creation of modern energy-saving technologies, in particular in woodworking sphere – drying chambers for drying of wood and other capillary-porous materials. The usage of computer-aided design systems and the engineering analysis – CAD/CAE – systems (Computer Aided Engineering) is one of possible ways of physical processes computer simulation in wood drying chambers. In this respect, the program systems integrated into CAD (systems of computer-aided design) are of importance, as well as they enable to research complex thermal-physical and aerodynamic processes in multicomponent anisotropic environments. The class of such systems includes COSMOSFloWorks which is based on updated achievements of calculating methods and is integrated along with SolidWorks computer-aided system of geometric design.

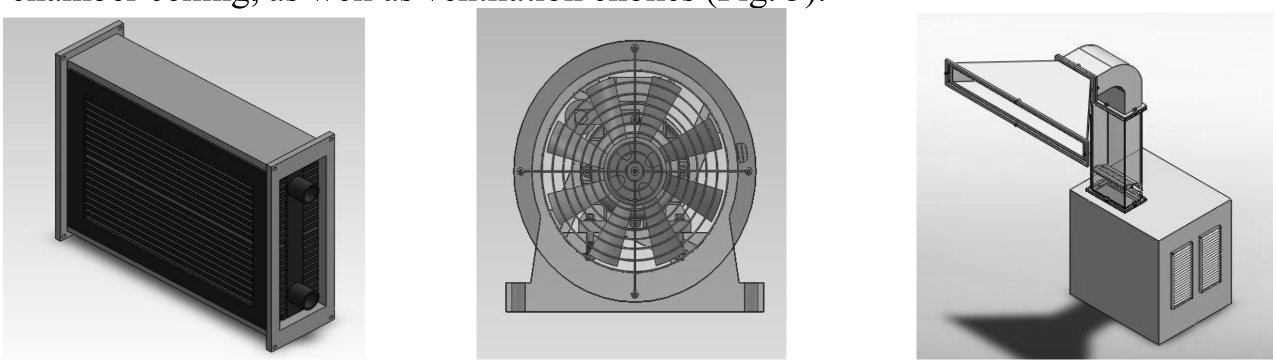
That is why the search for efficient ways on the design of lumber drying kilns is directly connected with the computer-aided design systems development on the basis of computer simulation and making optimal design solutions.

The analysis of the research. The analysis of the reference literature [2-4] and practice of the forest drying chambers design testify that the research of lumber drying kilns as the objects of the design and their computer simulation require further substantial improvement. Available mathematical models of heat-and-mass transfer in lumber drying kilns are based on material and thermal balances equations [2, 4] which determine heat-and-mass transfer of a coolant. On the basis of such an approach drying chambers computer simulation is realized mostly from the viewpoint of control systems [3]. It is necessary to indicate that computer models of the heat and mass exchange engineer analysis in lumber drying kilns are quite rare. Due to engineer analysis technologies CAE (Computer Aided Engineering), the capabilities of the numerical analysis have widely extended in connection with the intensive development of computer engineering and software for recent years. In terms of CAE there is such a class of programs as CFD (Computational Fluid Dynamics) designed for the computer analysis of physical fields [7, 8]. Such programs as COSMOSFloWorks, Fluent, Flowvision and others belong to this class. CFD programs proved themselves as being good for scientific research of heat and mass exchangeable fields in various branches of industry. The research shows the possibilities and expediency of the COSMOSFloWorks use in combination with SolidWorks for the drying chamber construction design, as well as the heat and mass transfer processes analysis in drying chambers. Virtual laboratories [5] have expanded greatly, though most of them are built using Java or other similar technologies and do not use specialized software. In particular, they are not designed for the work with popular CAD/CAM/CAE systems such as SolidWorks. It is vital to indicate such important capabilities of virtual mathematical laboratories as an interactive simulation, an experiment and parameters variation.

The last feature enables to directly observe the change of a researched object and control this change. Two objectives are achieved with the help of this: 1) a high interactivity level of environment in which a researcher works; 2) in the background of gradual changes of an object there are revealed its inherent regularities. Analyzing references literature, there appeared a task to create a peculiar virtual laboratory for the analysis of heat and mass transfer processes in drying chambers. For the sake of this, in terms of the given design a supplement was created on the basis of SolidWorks API (Application Programming Interface, API) and SolidWorks software package.

Setting the task. To design a three-dimensional geometric model of a sawn timber drying chamber by means of SolidWorks, COSMOSFloWorks, the interface SolidWorks API. To develop a program supplement for the control of chamber input parameters, results of conducted experiments, as well as three-dimensional model of lumber drying kilns and the parameters change of the charging wood stack.

In COSMOSFloWorks program medium to model the distribution of thermal fields in a chamber during the drying process of sawn timber. To research the distribution dependence of dried wood temperature and humidity, sawn timber imitation surfaces caused by different capacity degree and quantity of thermal radiators, air movement direction and speed in a chamber. The analysis of the means SolidWorks API. The SolidWorks 2011 computer-aided design system has been used to create the three-dimensional lumber drying kiln model. Its medium and tools are well adapted to the construction of complex surfaces and assemblages. For the experimental model construction the chamber of periodic action has been selected. The most important chamber elements, e. g. radiators (Fig. 1a), fans (Fig. 1b) and air supply systems (Fig. 1c) have been designed. After the design completion the assemblage of the solid model consists of the following: the quantity of fans and radiators set by a user, the false ceiling, the stack on a substack cart (Fig. 2), the air supply system (Fig. 1), the very chamber and the chamber ceiling, as well as ventilation chokes (Fig. 3).



a) b) c)

Fig. 1. Three-dimentional models of the chamber elements:

a) radiator; b) fan; c) air supply system

The created 3-D model of the lumber drying kiln corresponds to sizes of real chambers, the scale being 1:1 which significantly slows down the process of the imitation modelling. In order to avoid the great loss of time on each experiment, the model of reduced sizes has been worked out. The issues connected with the construction of specialized supplements, which provide the solution to applied scientific and engineering problems with the help of various program supplements integration with the aim of unique information system (IS) creation, become of special topicality.

The supplements integration is a more difficult task in comparison with the traditional data integration. However, the integration at a level of supplements possesses a list of indisputable advantages. They comprise, first of all, the providing with the continuous cycle of supplements information interaction in terms of IS; computer-aided execution of service supplements according to the instruction of IS base components; high speed of operation caused by the absence of the necessity in interim data formats**;** minimization of disk operations etc. That is why, one of thebasic requirements brought forward for the components of updated information system is the possibility of the program control of the functional means set realized in these components.

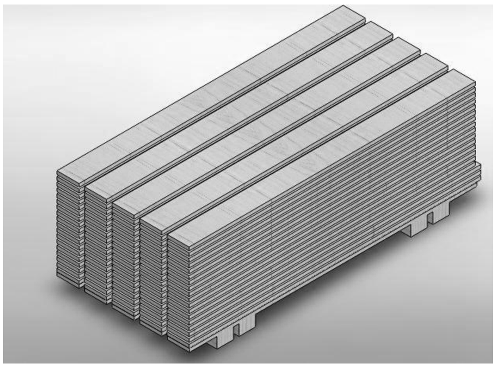


Fig. 2. 3-D stack model on a substack cart

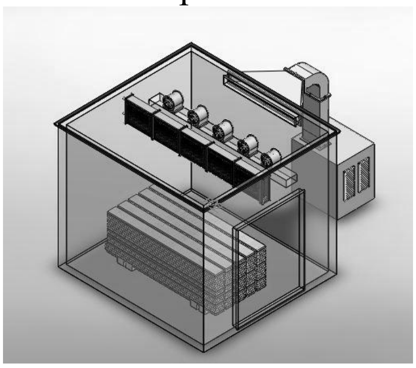


Fig. 3. Solid 3-D model of a lumber drying kiln of periodic action in assemblage worked out by means of Solid Works

In other words, the application programming interface (API) availability in this or that supplement is necessary and sufficient for the solution of the informational system components integration problem at a level of supplements. SolidWorks API is an applied programming interface which enables to develop user programs at the platform of SolidWorks. API comprises hundreds of functions which are possible to envoked out of such programs as Microsoft Visual Basic, VBA (Microsoft Excel, Word, Access etc.), Microsoft Visual C, C++, C#, .NET or SolidWorks files-macros. API-functions provide direct program access to functional capabilities of SolidWorks packet.

Applied programming interface is presented in the composition of CAD SolidWorks base configuration. Except the base design solution API is included into all basic modules (Toolbox, FeatureWorks, Utilities, PhotoWorks, eDrawings, Routing, SWR-PDM, SWR-Electrics) forming a part of SolidWorks packet. Dynamic libraries of types and constants responsible for the API work are automatically installed onto a computer at the program installation. In such a way every CAD Solid Works working place according to the default is equipped with applied programming interface which gives a wide range of possibilities to developers. In a reference system it is possible to find a detailed description of API structure, as well as a list of new functions added to API before the moment of updated SolidWorks description version appearance (Fig. 4). The reference is invoked out of “Reference sections on SolidWorks and API modules” menu. The reference system is expanded by a set of samples «SolidWorks API SDK» (Software Development Kit developer’s set) updated at the appearance of every new version of Solid Works.

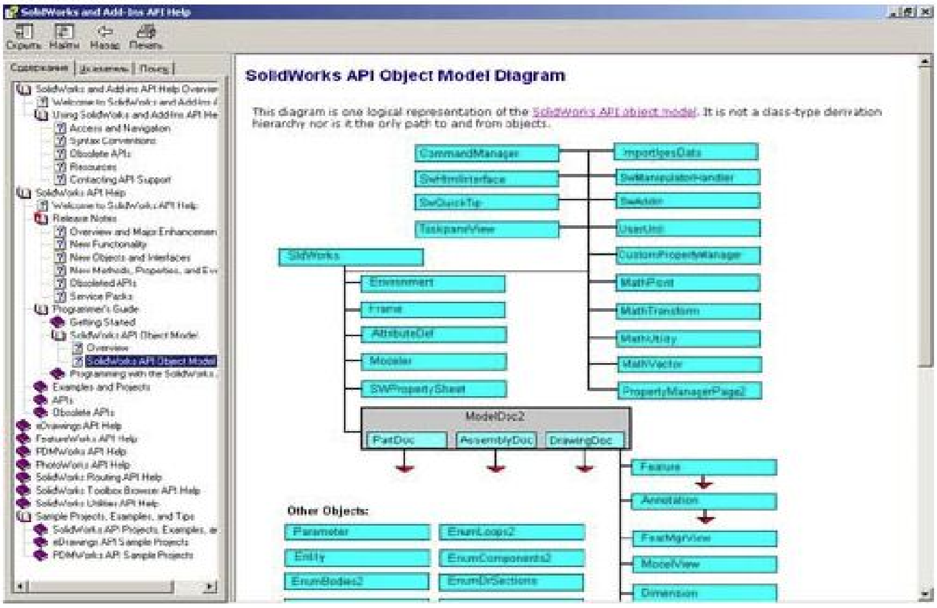


Fig. 4. The reference system SolidWorks API

The development of the program supplement Wood v1.0. It is essential to have an access to Solid Works API out of Microsoft Visual Studio 2010 for the development of the program supplement Wood v1.0. Therefore, there is a neced for setting corresponding libraries which can be downloaded from the official site of Solid Works. The next step is running the program Solid Works and the activation of the supplement SolidWorks Simulation. Thereafter, it is necessary to open the assemblage which contains a designed 3-D model of the lumber drying kiln and then run Wood.exe.

The model of the chamber and the applied program are located in the root directory of the design. Every model is a separate informational core. The model has a convenient graphical interface with different controlling elements with the help of which a user may change parameters what permits to analyze its behavior under different conditions. During the activation of the program, a screensaver, which collects necessary resources for further work of the program appears (Fig. 7).

Fig. 7. The interface of the supplement Wood v1.0

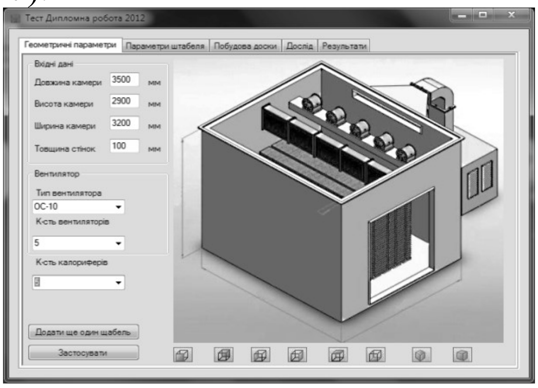


Fig. 8. The interface inset "Geometric parameters of lumber drying kilns"

With the help of the interface inset "Geometric parameters of lumber drying kilns" (Fig. 8) a user may set geometric sizes of the chamber, as well as indicate the quantity of fans, radiators and increase the quantity of boards in a stack.

In Fig. 9 we can see that the stack parameters of the wood are taken into account, in particular: material, the thickness of a board, the sickness of spacing (between boards in the stack), the distance between rows of boards, the height of the stack, the length of the input board. In the following insets it is possible to set input parameters for modeling, as well as reflect the findings.

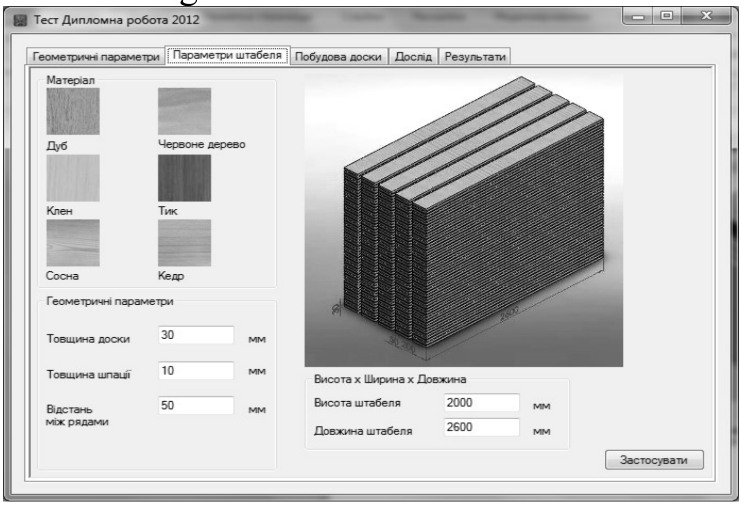


Fig. 9. The interface of the inset "Parameters of the stack"

Mathematical modeling of the lumber drying kiln object by means of COSMOSFloWorks. After the 3-D model of the chamber has been fully designed in Solid Works medium, it is possible to begin the computer-aided calculation of physical fields in the forest drying chamber.

However, the more surfaces and objects in the calculation area, the more hardware resources will be required for the calculation. In order to economize on these factors, a simplified model of the chamber has been developed, on the basis of which calculations have been conducted. For the beginning of the computer-aided calculation it is necessary to create a design in COSMOSFloWorks, set input data, as well as initial and boundary conditions. Therefore, the following steps have been taken in COSMOSFloWorks:

- as usual, first of all setting the name of the design;
- choosing a unit of measurement system. In our case it is the system SI. For convenience, we change the temperature indication from K to °C;
- choosing a problem type: either internal or external. An internal problem is the sawn timber change calculation in a stack. And an external one is the chamber drying agent parameters modeling which influence on the internal problem solution;
- choosing a substance type inside the model. In our case it is Air;
- choosing materials for details included into our assemblage. There is no wood in a standard library of COSMOSFloWorks. Therefore, there have been created and added to the database such materials as: maple, oak, pine, mahogany, teak and cedar;
- the next step is setting the surfaces thermal-physical parameters of the model. For example, coefficients of thermal conductivity, initial temperature of external air and other characteristics;
- setting thermal-physical and aerodynamic parameters of radiators and fans;
- defining the accuracy of the findings. Therefore, we take advantage of the created irregular grid for the method realization of the finite elements.

As soon as the design is created, it is necessary to insert corresponding input data in the control bar of FloWorks, in particular: pressure (static) − 101325 Pa, initial temperature of air in a chamber – 20°C and other parameters. Heating of air is realized by radiators in a chamber. We install their capacity: approximately 2 kW. Air flows are sent under the action of axial fans in the direction of radiators with the angular velocity of 100 r/s. It is also necessary to set physical parameters of the chamber elements and thermal conductivity. It is vital to indicate that the integration of COSMOSFloWorks with SolidWorks is required for such an approach. It permits to conduct the computer-aided calculation of the researched physical fields in the lumber drying kiln without additional lines of the data transfer between the program coverings of the object geometric design and mathematical modeling, as well as calculation. The tasks of the data-in and the visualization are realized directly in the medium of SolidWorks.

The analysis of the findings. The computer-aided calculation system COSMOSFloWorks can receive results in graphics which makes them more available and comprehensible. In its turn the developed supplement enables to research variants as much as possible due to the change of input parameters for each new research. During the modeling process of lumber drying kiln elements work it is possible to observe the temperature change in a chamber with every calculation iteration in real-time.

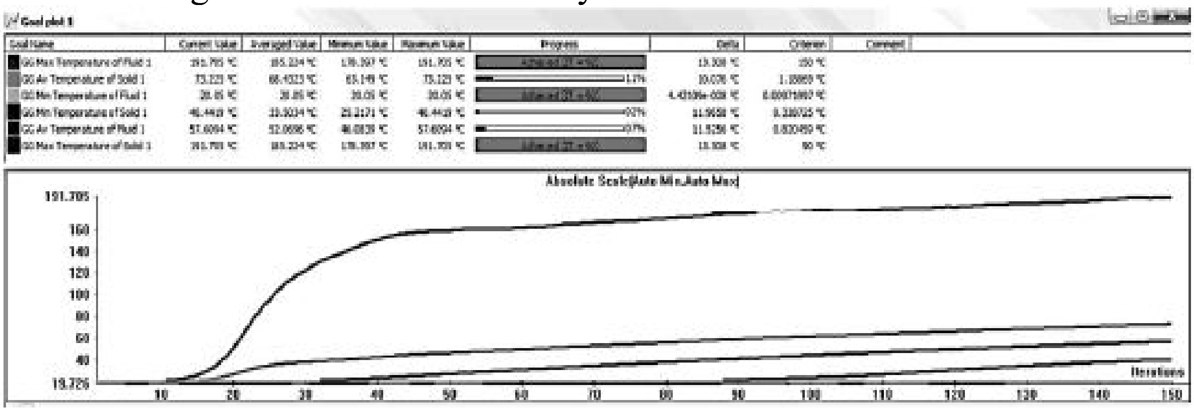


Fig. 11. Interim temperature denotations results concerning the time of research conducting

In the upper part of Fig. 11 demonstrated are denotations of all the parameters which we have set as the goals of the calculation. And in the lower part they are illustrated graphically. In the diagram we can trace the air and chamber surfaces temperature change caused by the heating of the radiator. Initial air temperature is 20 °C inside the chamber.

With time, it begins to grow, surfaces temperature starts to grow as well. After the 20 time units mark we can observe the way air temperature rapidly goes up (it is connected with the mixture of heated steams and air which reached the chamber) and the stack surface temperature rises as well but fluently and gradually. COSMOSFloWorks enables to research corresponding parameters in necessary chamber spots and at any moment of time. The system also emits results for other researched parameters, such as speed, pressure, density, flows intensity.

Conclusions. The possibilities of SolidWorks API, COSMOSFloWorks application for 3-D design of the forest-drying chamber in the process of wood drying have been demonstrated. In particular, in research:

- the 3-D model of the lumber drying kiln and its components have been developed;
- there have been set the input parameters for the modeling: parameters of radiators and fans, air temperature inside and outside the chamber, air pressure, characteristics of chamber materials and objects in it;
- the wood drying process, in particular the distribution of air and thermal steams in the chamber and wood have been modelled;
- the modeling findings in both numerical and graphic form have been received and analyzed.

The great contribution of the interface SolidWorks API is worth taking into account due to which the program system for the modeling conducting of interactive experiments has been developed, as well as a quite simple and convenient in usage graphic interface for a user which permits to take advantage of all the functions of the given system.

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УДК 681.3.06:674.047 ***Проф. Я.І. Соколовський д-р техн. наук; ассист. І.Б. Борецька, інж. П.І. Рожак – НЛТУ України***

Інформаційні технології проектування та дослідження лісосушильних камер засобами SolidWorks API і COSMOSFloWorks

Для твердотілого моделювання лісосушильної камери та створення тривимірних моделей її компонентів використано систему автоматизованого проектування SolidWorks 2011. Розроблено програмно-орієнтований комплекс “Wood v.1.0” на основі SolidWorks API, з використанням компілятора Microsoft Visual studio 2010, який дає можливість досліджувати параметри камери, а також керувати геометрією лісосушильної камери та штабеля. Здійснено тепловий розрахунок та аналіз фізичних потоків у лісосушильній камері з використанням інформаційних технологій проектування COSMOSFloWorks.
Ключові слова: САПР, SolidWorks, SolidWorks API, COSMOSFloWorks, модель, лісосушильна камера, процес сушіння, температура.

UDC 621.39:674.047 ***Prof. Ya.I. Sokolovskyy, I.M. Kroshnyy, prof. M.M. Stadnyk – UNFU***

MATHEMATICAL MODELING AND OPTIMIZATION IN THE PROCESS OF DRYING CAPILLARY-POROUS MATERIALS

Carried out is numerical implementation of the mathematical model for the stress-strain state and temperature and moisture fields in the process of drying capillary-porous materials and formulated optimization problem. The analysis of function selection for the purpose of building technological modes of drying capillary-porous materials is made. The method of construction and investigated continuous modes of drying by solving the optimization problem has been presented.
Keywords: mathematical model, the stress-strain state, capillary-porous material, optimization problem, the objective function, modes of drying.

The relevance of this work. The decisive factor in the intensification of the drying process while increasing quality materials dried is the drying mode. The proper selection and compliance with environmental parameters as close to the target level, depending on the state of the material – its humidity and internal stress, which are dependable quantitative and qualitative indicators of the drying process. Developing optimal technological regimes to achieve the required level of quality drying is an urgent problem nowadays, one way to solve this is the construction of mathematical models that allow you to control moisture content of the material and the development of internal stresses.

Application of multi modes of drying wood is characterized by a number of disadvantages associated with the negative impact of modified dry (ambient temperature, relative humidity and velocity of air circulation) on the physical and mechanical properties of wood and reduced quality products that are dried. In addition, to minimize such effects requires increasing the capacity of heating equipment drying chambers.

Analysis of known results. Most studies on optimization of processes related to wood drying deals with optimization performance of various drying chambears process automation. And almost no relation to a construction of optimum drying in terms of physical and mechanical processes in the wood, which are crucial to ensure product quality. Most regimes of drying were constructed empirically, and later improved, optimized for economic or technical criteria. Accordingly known optimization criteria are divided into economic, technical and technological [5, 17].

Mathematical model and optimization problem formulation. One way to intensify and improve drying capillary-porous materials, including wood, is the development of continuous control heat and moisture exchange that would be realized using modern tools. The basis of this approach is the justification and optimization of continuous technological modes of drying wood.

Structure continuous (step less) regimes fre characterized by performance conditions $(t_c(U(\tau)) - U_p\ (U\ (\tau)))^2$, where t_c – ambient temperature, U, U_p – humidity and equilibrium moisture content, τ – drying time.

In previous works [2, 3, 4, 6] investigated are the patterns and processes of heat-and-mass transfer, deformation of capillary-porous materials during their drying considering elastic, viscoelastic and plastic deformations. Within the object-oriented approach, developed is software for numerical implementation and finite-element analysis of mathematical models [4, 7]. Two-dimensional mathematical model for changing the duration of of drying period $\tau \in [0, \tau_c]$ in $\Omega = \{x = (x_1, x_2);\ x_i \in [0, l_i],\ i = 1, 2\}$, which is a rectangular cross-section wooden beams with geometrical dimensions l_1, l_2, we consider for two reasons: firstly, the deformation arising in wood that is dried in plain and radial directions of anisotropy is much higher than the strain in the fiber direction and is a major source of defects, and secondly, the size of timber along the fibers are almost always considerably larger than the sizes across the grain.

Based on mathematical models of viscoelastic deformation and processes heat and mass transfer in capillary-porous materials, taking into account thermomechanical characteristics we formulate the optimization problem for constructing continuous technological modes of drying wood in this way.

We to find such features as ambient temperature $t_c(x, \tau)$ and relative humidity $\varphi(x, \tau)$ with regard to their limits $t_{c1} \le t_c(x,\tau) \le t_{c2}$; $\varphi_1 \le \varphi(x,\tau) \le \varphi_2$ (1)

and the stress-strain state $|\sigma_{11}(x,\tau)| \le \sigma_{11_\Gamma}$; $|\sigma_{12}(x,\tau)| \le \sigma_{12_\Gamma}$; $|\sigma_{22}(x,\tau)| \le \sigma_{22_\Gamma}$, (2)

that for wooden beams with an initial moisture content of $U(x, 0) = U_0(x)$ over a given drying time to minimize the condition $J(U) = (t_c(U(x,\tau)) - U_p(U(x,\tau)))^2 \to \min$, (3)

where t_{c1}, t_{c2}, $\sigma_{11\Gamma}$, $\sigma_{12\Gamma}$, $\sigma_{22\Gamma}$ – set values.

To determine the temperature and moisture heat and mass transfer mathematical model is:

$$c\rho\frac{\partial T}{\partial\tau}=\frac{\partial}{\partial x_1}\left(\lambda_1\frac{\partial T}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(\lambda_2\frac{\partial T}{\partial x_2}\right)+\varepsilon\rho_0 r\frac{\partial U}{\partial\tau};$$
$$\frac{\partial U}{\partial\tau}=\frac{\partial}{\partial x_1}\left(a_1\frac{\partial U}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(a_2\frac{\partial U}{\partial x_2}\right)+\frac{\partial}{\partial x_1}\left(a_1\delta\frac{\partial T}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(a_2\delta\frac{\partial T}{\partial x_2}\right). \quad (4)$$

Initial conditions: $U\big|_{\tau=0}=U_0(x_1,x_2);\ T\big|_{\tau=0}=T_0(x_1,x_2).$ (5)

Boundary conditions:

$$\lambda_i\frac{\partial T}{\partial n}\bigg|_{x_i=l_i}+\rho_0(1-\varepsilon)\beta_i\left(U\big|_{x_i=l_i}-U_p\right)=\alpha_i\left(t_c-T\big|_{x_i=l_i}\right);\quad \frac{\partial T}{\partial n}\bigg|_{x_i=0}=0;$$
$$\left(a_i\frac{\partial U}{\partial n}+a_i\delta\frac{\partial T}{\partial n}\right)\bigg|_{x_i=l_i}=\beta_i\left(U_p-U\big|_{x_i=l_i}\right);\quad \left(\alpha_i\frac{\partial U}{\partial n}+\alpha_i\delta\frac{\partial T}{\partial n}\right)\bigg|_{x_i=0}=0;\quad i=1,2. \quad (6)$$

In this case $T_0(X)$, $U_0(X)$ – the initial distributions of temperature and moisture content in the material; $U_p(T_c,\varphi)$ – the equilibrium humidity; $c(T,U)$ – heat; $\rho(U)$ – density; $\lambda_i(T,U))$ and $a_i(T,U)$ – respectively the coefficients of thermal conductivity and humidity conduction in the direction of anisotropy; ε – rate of phase transition; ρ_0 – basic density; r – specific heat of vaporization; $\delta(T,U)$ – thermogradient coefficient, in the direction of anisotropy; $\alpha_i(T_c,v)$ and $\beta_i(T_c,\varphi,v)$ – coefficients of heat and moisture, respectively; T_c – ambient temperature; $\varphi(\tau)$ and $v(\tau)$ – relative humidity and velocity of the drying agent, respectively; n – vector of external normal border region Ω. The initial distribution of moisture in the wood in the period irregular mode of drying is taken constant, and during the regular regime it change by a parabolic law.

Vector components of stresses $\sigma_{ij}=(\sigma_{11},\sigma_{22},\sigma_{12})$ satisfy equilibrium equation:

$$\frac{\partial\sigma_{11}}{\partial x_1}+\frac{\partial\sigma_{12}}{\partial x_2}=0;\quad \frac{\partial\sigma_{12}}{\partial x_1}+\frac{\partial\sigma_{22}}{\partial x_2}=0. \quad (7)$$

Boundary conditions take into account the absence of external forces:

$$\sigma_{ij}\big|_{x_1=l_1,\,x_2=l_2}=0. \quad (8)$$

Modeling viscoelastic stresses and deformations in wood during drying, shrinkage is based on the laws of absorbent material and integral equations of the theory of genetic Boltzmann-Voltaire and the formula:

$$\sigma_{11}(\tau)=C_{11}(T,U)[\varepsilon_{11}(\tau)-\varepsilon_{U1}]-C_{11}(T,U)\int_0^\tau R_{11}(\tau-s,T,U)[\varepsilon_{11}(\tau)-\varepsilon_{U1}]ds+$$
$$+C_{12}(T,U)[\varepsilon_{22}(\tau)-\varepsilon_{U2}]-C_{12}(T,U)\int_0^\tau R_{12}(\tau-s,T,U)[\varepsilon_{22}(\tau)-\varepsilon_{U2}]ds;$$
$$\sigma_{22}(\tau)=C_{21}(T,U)[\varepsilon_{11}(\tau)-\varepsilon_{U1}]-C_{21}(T,U)\int_0^\tau R_{21}(\tau-s,T,U)[\varepsilon_{11}(\tau)-\varepsilon_{U1}]ds+ \quad (9)$$
$$+C_{22}(T,U)(\varepsilon_{22}(\tau)-\varepsilon_{U2})-C_{22}(T,U)\int_0^\tau R_{22}(\tau-s,T,U)[\varepsilon_{22}(\tau)-\varepsilon_{U2}]ds;$$
$$\sigma_{12}(\tau)=2C_{33}(T,U)\varepsilon_{12}(\tau)-2C_{33}(T,U)\int_0^\tau R_{33}(\tau-s,T,U)\varepsilon_{12}(s)ds,$$

where: $\varepsilon_U = (\varepsilon_{U1}, \varepsilon_{U2}, \varepsilon_{U3})^T$ – vector component deformations that occur due to changes in temperature and moisture, C_{ij} – tensor components of anisotropic elastic body. Values ε_{Ui}, C_{ij} are defined by the formulas:

$$\begin{bmatrix} \varepsilon_{U1} \\ \varepsilon_{U2} \\ 0 \end{bmatrix} = \begin{bmatrix} \alpha_1 \Delta T + \beta_1 \Delta U \\ \alpha_2 \Delta T + \beta_2 \Delta U \\ 0 \end{bmatrix}; \qquad \mathbf{C} = \begin{bmatrix} \dfrac{E_1}{1-\upsilon_1\upsilon_2} & \dfrac{\upsilon_1 E_2}{1-\upsilon_1\upsilon_2} & 0 \\ \dfrac{\upsilon_1 E_2}{1-\upsilon_1\upsilon_2} & \dfrac{E_2}{1-\upsilon_1\upsilon_2} & 0 \\ 0 & 0 & \mu \end{bmatrix},$$

where: ΔT, ΔU – accordance with increase in temperature and moisture, $E_i(T,U)$ – Young's modulus, $v_i(T,U)$ – Poisson's ratios, $\mu(T,U)$ – shear modulus.

Functions rheological behavior of wood during drying with regard to the mechanism of accumulation of irreversible strains are selected as

$$\varepsilon^*(\tau) = \left[a_0 - \sum_{i=1}^{M} a_i \exp(-b_i \tau) \right] h(\tau) h(\tau_0 - \tau) - \left[a_0 - \sum_{i=1}^{M} \alpha_i \exp(-\beta_i (\tau - \tau_0)) \right] h(\tau - \tau_0), \quad (10)$$

where: $h(\tau)$ – Heaviside function, and the unknown coefficients a_i, b_i, α_i, β_i determined by least squares approximation based on experimental data of creep samples of wood under load and after unloading [11].

To simulate the mechanical and sorption strain caused by changes in humidity rate applied in equation [16]:

$$\frac{\partial \varepsilon_M}{\partial \tau} = m\sigma \left| \frac{\partial U}{\partial \tau} \right|, \quad (11)$$

where m – parameter model. Dependence of Mechanical and sorption flexibility to changes in humidity by dependence:

$$J_m = \frac{1}{E_m}\left(1 - \exp(-\upsilon_0 m_1 E_m)\right) + m_2 \upsilon,$$

where E_m, υ_0, m_1, m_2 – model parameters, which are determined from experimental studies.

To simulate the plastic properties of wood, Prandtl-Reis' theory of plastic flow is used [14]:

$$de_{ij} = s_{ij} d\lambda + \frac{ds_{ij}}{2\bar{\sigma}}; \quad d\lambda = \frac{3}{2} \frac{d\varepsilon^{пл}}{H\bar{\sigma}};$$

$$d\varepsilon^{пл} = \frac{3}{2}\sqrt{d\varepsilon_{ij}^{пл} d\varepsilon_{ij}^{пл}}; \quad H = \frac{d\bar{\sigma}}{d\varepsilon^{пл}}; \quad \bar{\sigma} = \sqrt{\frac{3}{2} s_{ij} s_{ij}},$$

where e_{ij}, S_{ij} – devitatory strains and stresses.

According to the laws of plasticity [14], we can write a relation between the differentials of stresses and strains:

$$d\sigma_{ij} = \frac{E}{2(1+v)}\left(d\varepsilon_{ij} + \frac{v}{1-2v}\delta_{ij} d\varepsilon_{ij} - s_{ij}\frac{s_{ke} d\varepsilon_{ke}}{s} \right), \qquad s = \frac{2}{3}\bar{\sigma}^2\left(1 + \frac{2(1+v)}{3E}\right), \quad (12)$$

where δ_{ij} – Kronecker symbol.

Value (7) – (12) constitute the mathematical model of viscoelastic deformation of capillary-porous materials during drying with regard to the accumulation of irreversible deformation. For the numerical implementation of the model, finite element method is used [4, 15].

Analysis of simulation results. To solve the formulated optimization problem (1) – (3) the method of genetic algorithms is used. In accordance with the basic definitions and provisions of the theory of genetic algorithms [5, 10] for solving the need to specify the form of chromosomes, which represent a solution and requires fitness function to be determined by the most appropriate chromosome is the best solution.

To simulate the temperature dependence of the medium, we use

$$t_c(U(x,\tau)) = t_0(x) + (t_k(x) - t_0(x))\frac{U_0(x) - \overline{U}(\tau)}{U_0(x) - U_k(x)}, \tag{13}$$

where: t_k – final value of ambient temperature, U_k – final value of the moisture content.

An expression that binds moisture equilibrium with the function of moisture content according to [10] can be written as

$$U_p = U_{p\kappa} + (U_{pn} - U_{p\kappa})\exp(-\exp(b_1 + b_2\, U(x,\tau))), \tag{14}$$

where: $U_{p\kappa}$, U_{pn} – equilibrium moisture content at the beginning and at the end of the drying process, b_1, b_2 – some coefficients that are determined by the empirical relationship [10].

Thus, the temperature and humidity of the environment of drying vary from linear (13) and exponential (14) dependencies. The corresponding chromosome genetic algorithm has the for $\chi = (\tau_1, ..., \tau_{k-1}, t_{c1}, t_{c2}, ..., t_{ck}, U_{p1}, U_{p2}, \ldots, U_{pk})$. (15)

Fitness function written as

$$P(\tau_1, ..., \tau_{k-1}, t_{c1}, t_{c2}, ..., t_{ck}, U_{p1}, U_{p2}, \ldots, U_{pk}) = \begin{cases} 0, & \max \sigma_{ij} \geq 75\% \cdot \sigma_{\Gamma M}; \\ J(U), & otherwise, \end{cases} \tag{16}$$

where $\sigma_{\Gamma M}$ – experimentally determined boundary strength of wood [1].

Numerical solution of an optimization problem is done by using Mathlab 7.01 Genetik Algorithm and Direct Search Toolbox, which is used for the expansion Optimization Toolbox genetic algorithms [9].

For the calculation input was taken pine wood (dry mass density $\rho_0 = 470$ kg/m^3). Geometrical dimensions l_1 and l_2 chosen different, particularly $l_1 = l_2 = 25$ mm; $l_1 = 2l_2 = 50$ mm; $2l_1 = l_2 = 50$ mm. Initial moisture $U_0 = 0.3$ kg/kg coefficients mass conductivity and moisture were determined by approximating dependencies [17]: $\alpha_1 = [0.527(t_c + 10)^{2.06} \cdot 10^{-6} + 0.04[(5v + 3.5) - (0.0017v + 0.0116)(\varphi - 45)^2] \cdot 10^{-7}$; $\alpha_1 / \alpha_2 = 1.25$; $\alpha_1 = 10^{9.36 \lg(t+273) - 22.6} \cdot 10^{-10}\ м^2/c$. To calculate the chosen constant temperature for which $t_c = 75$ºC; $\varphi = 0.3$; $v = 2$ m/c. The equilibrium moisture content was determined by the formula $U_p = 10.6^{\varphi}(0.0327 - 0.00015 t_c)$. The coefficients of the linear shrinkage in the radial and plain areas in formulas (6) are respectively $\beta_1 = 0.17$ and $\beta_2 = 0.28$, and the coefficients α_1 and α_2 in formulas (6) are equal to zero. Odds Poisson $v_{12} = 0.4$; $v_{24} = 0.4$; $v_{13} = 0.4$, and Young's modulus – $E_1 = 1200 + 31.30U + 9.5T + 24.2UT$; $E_2 = 1.6E_1$. Other thermophysical properties of pine wood are given in [17]. For approximable dependency functions rheological behavior of wood $R(t, \tau)$ the results of studies were used [11]. Also based on experimental studies [12, 13] for wood pine, module plasticity in the ratio (9) $E_{пл} = 188$ MPa for the humidity 12% and $E_{пл} = 237$ MPa for moisture 4% were used. The value of v was assumed to be equal to 0.5. According to [12] the value of liquid limit equals to $\sigma_{\Gamma T} = 3.2 \cdot 10^6$ Pa.

The results of the numerical solution of the optimization problem are shown in Figure 1. to compare the influence of the regime and the regime with constant parameters of the environment on the drying process of wood; shown is the distribution of stresses in the surface and central layers of wooden model.

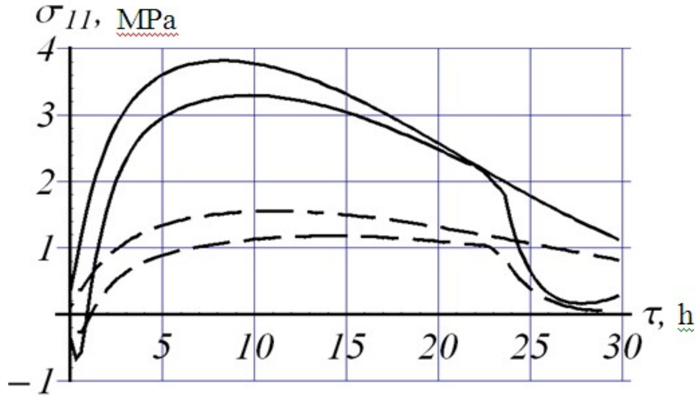

Fig. 1. The development of normal stresses in the surface (- – - -) and central layers (——) of wood under optimized mode and constant environmental parameters

Fig. 2 shows the relatioship of the duration of the drying process wich the initial value of the equilibrium moisture content of wood $U_{рп}$ and its final value $U_{рк}$, taking into account the temperature of drying agent.

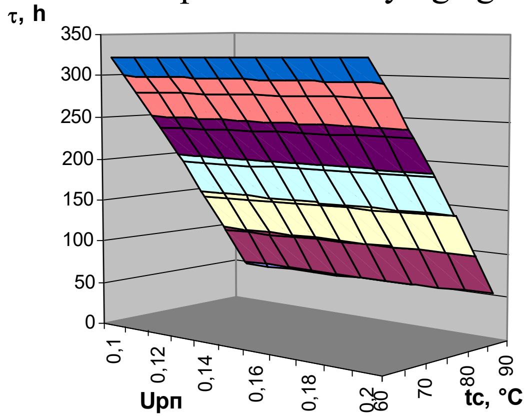

Fig. 2. Dependence of the duration of the drying process variables $U_{рп}$ and t_c for value $U_{рк}$ = 0,035

Conclusions. Based on the mathematical model study of the stress-strain state and temperature and moisture patterns optimization problem of drying capillary-porous materials has been formulated. A target of minimizing the difference between the temperature of drying medium and the equilibrium moisture content of wood with constraints on stress has been shown.

Using genetic algorithms, the optimization problem that can improve the quality of drying capillary-porous materials, including wood (lower humidity difference in thickness of the material and the magnitude of the stress-strain state) has been solved.

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УДК 621.39:674.047
Проф. Я.І. Соколовський, д-р техн. наук; асист. І.М. Крошний; проф. М.М. Стадник, д-р техн. наук – НЛТУ України

Моделювання та оптимізація процесу сушіння капілярно-пористих матеріалів

Здійснена чисельна реалізація математичної моделі напружено-деформівного стану та температурно-вологісних полів у процесі сушіння капілярно-пористих матеріалів та сформульована задача оптимізації. Проаналізовано вибір функції мети для побудови технологічних режимів процесу сушіння капілярно-пористих матеріалів. Наведено методику побудови та досліджено безперервні режими процесу сушіння за рахунок розв'язання задачі оптимізації.

Ключові слова: математична модель, напружено-деформівний стан, капілярно-пористий матеріал, оптимізаційна задача, функція мети, режими сушіння

UDC 674.021
Assoc. prof. A.S. Kushpit; master`s degree V.V. Kostyuk; assist. O.M. Kushpit – UNFU

STATISTICAL ANALYSIS OF THE FURNITURE BOARD MANUFACTURING PROCESS FOR THE PURPOSE OF QUALITY IMPROVEMENT

The process of manufacturing furniture board using statistical methods is analysed.
Keywords: process, statistical analysis, quality.

The most important source of efficiency increase of manufacturing process is constantly improvement of the technical level and quality of products. In Ukraine statistical methods of quality control are becoming relevant, and the positive experience of applying them has existed in the world in the second half of the last century.

A necessary condition for the implementation of statistical methods is the involvement of all business units and quality control at all stages of the production cycle: from raw materials to finished products. The study treats the problems: analysis of quality requirements concerning blanks and finished furniture shields; analysis of defects arising in the technological process of furniture board manufacturing; conducting statistical research; development of statistical research methodology as well as recommendations to reduce defects. Analysing the requirements for quality, defects were found at stations producing laminated furniture board – the presence of defective lamellas and defects in furniture board. The defects were classified by their type, the place of their formation, machines. It was found out that the defects appear during the formation of cross-section slats; draft board calibration, trimming the size of the perimeter, sanding edges.

In lamellas the following defects were observed:

- width edge step;
- correct transverse streaks on the processed surface;
- transverse groove on the surface near the end;
- torn fibres;
- burning.

For statistical studies, data recording sheets were developed, the data were analysed. The results were recorded into the corresponding tables, see details:Table 1. An example table to construct Pareto chart is shown in Table 2. Pareto diagram is shown in Fig. 1. Also, we analysed data from the day of the week for controlled traits that are the most numerous– step according to width edges and transverse geometrically correct streaks on the processed surface.

Table 1. Observations. Cross-section formation site

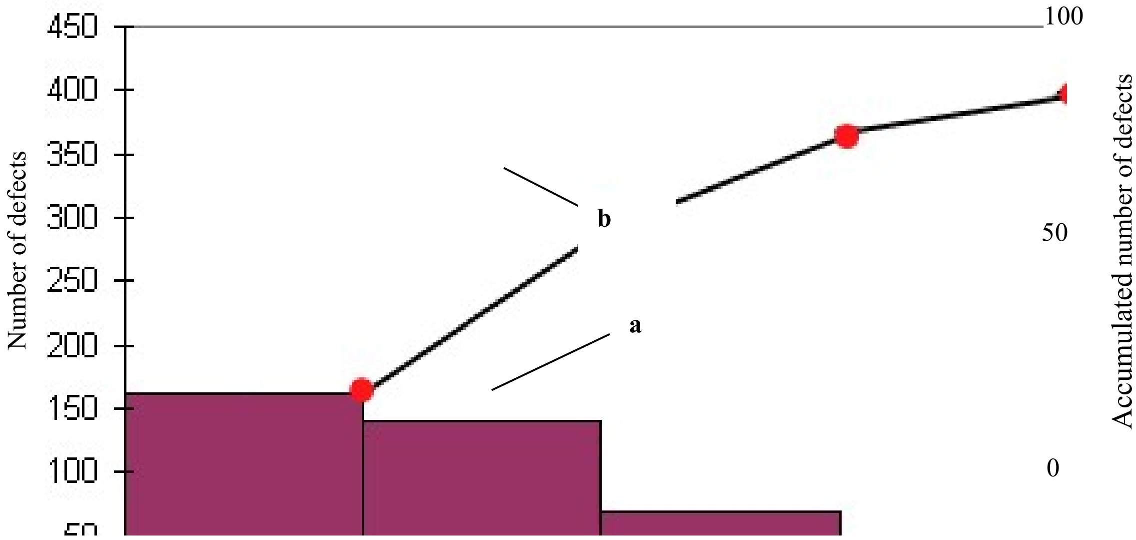
Total number of observations – 3000 blanks. Time of observations from 21 to 25 January

Equipment	Shift	Defect	Quantity of registered defects				
			Days of the week				
			1	2	3	4	5
Quadri-lateral Machine MB 4015 x 5	I	Transverse groove on the surface near the end	8	10	16	18	18
		Burning	4	3	5	8	3
		Torn fibres	3	2	6	9	8
		Transverse streaks on the processed surface	40	32	29	22	17
		Width edge step	30	21	19	48	43

Table 2. Table data to construct Pareto chart (site formation cross-section lamellas)

Controlled traits	Number of observations	Accumulated number of observations	Percentage of observations for each type	Accumulated percentage
Width edge step	161	161	38,15	38,15
Transverse streaks on the processed surface	140	301	33,17	71,32
Transverse groove on the surface near the end	70	371	16,6	87,92
Torn fibres	28	399	6,63	94,55
Burning	23	422	5,45	100
Total	422	-	100	-

Pareto chart for signs of defects. Number of observations – 3000. Observation period of Jan. 21 to Jan. 25



Defect signs: 1 – Width edge step; 2 – Transverse streaks on the processed surface; 3 – Transverse groove on the surface near the end; 4 – Torn fibres; 5 – Burning

Fig. 1. Pareto chart for signs of defects: *a – Bar chart; b – cumulative curve*

Table 3. Data analysis of the most important traits controlled by days of the week

Controlledtraits	Days of the week				
	1	2	3	4	5
Width edge step	30	21	19	48	43
Transverse streaks on the processed surface	40	32	29	22	17

As you can see, the largest number of defects in the formation of the cross-section lamella is width edge step (38.15%), a smaller percentage, with the difference of 5% from the previous sign, is transverse streaks on the processed surface (33.17%), transverse grooves on the surface near end (16.6%) and we get the least amount of defect from the trait – torn fibres due to skew layers (6.63%), burning (5.45%).

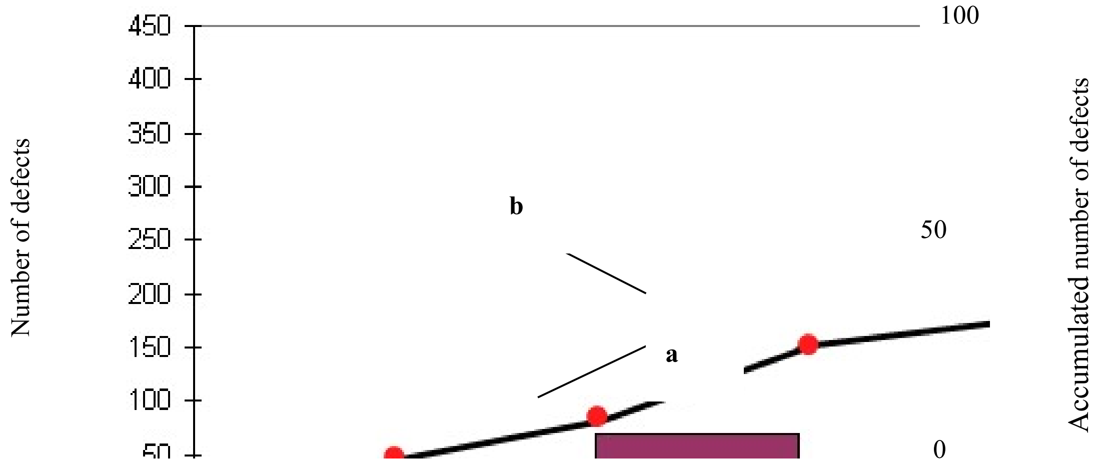
The analysis of the data depending upon the day of the week for the above controlled signs showed that: according to the first sign of the first day of the week the number of defects is 30 – this is due to the worker and correspondingly to the inproper adjustment of clamping rollers that create this defect. In the middle of the week, when we reached stability in the work, gradual decrease of defect is observed – 21 and 19. The end of the week is characterised by an increase of defects in lamellas, due to fatigue of the worker, his psychological condition and bad adjustment of clamping mechanisms – 48 and 43.Analysing the second sign we see that the number of defects during the week is gradually decreased, this is due to the highly qualified worker, the number of defective blades decreased by half in comparison with the beginning and the end of the week. The cause of this defect is a strong pinning of corrugated roller as well as a small size of the layer, which is removed.

Let us analyse the following three controlled features:

- transverse groove on the surface near the end, the cause of this defect is a strong pinning of smooth rear roller and insufficient pinning of corrugated rollers at the front end of the work piece;
- torn fibres due to skew layers. To correct this defect, it’s necessary to rotate the work piece by 180° to the vertical axis;
- burning wood. This defect appears because of the wood friction during the contact with a smooth roller.

After analysing the causes of defects the list of the main factors leading to defectwas compiled and the diagram of causes and results was constructed. Primary and secondary causes were estimated and removed as they affect the product quality, and new observations were conducted. Pareto chart for signs of defect after the elimination of defect causes.Fig. 2.

Pareto chart for signs of defect. Number of observations – 3000. Observation period of Mar. 2 to Mar. 9



Defect signs: 1 – Width edge step; 2 – Transverse streaks on the processed surface; 3 – Transverse groove on the surface near the end; 4 – Torn fibres; 5 – Burning

Fig. 2. Pareto chart for signs defects: *a – Bar chart; b – cumulative curve*

Conclusions: Of the total number of defects found the most important were:

1) Width edge step (38.15%), 2) Transverse streaks on the processed surface (33.17%). After analysing the charts of the causes and results, and also after the elimination of the major factors affecting the quality – precision in size as to the cross-section, the defect by the first sign was reduced to (21.67%), and by the second to (18.7%). Consequently, we conclude that a new quadrilateral machine that is used to produce the cross-sectional slats needs to be installed.

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УДК 674.021
Доц. А.С. Кушпіт, канд. техн. наук; магістр В.В. Костюк; асист. О.М. Кушпіт – НЛТУ України

Статистичний аналіз технологічного процесу виготовлення меблевого щита з метою покращення якості

Проаналізовано технологічний процес виготовлення меблевого щита з використанням статистичних методів.

Ключові слова: технологічний процес, статистичний аналіз, якість.

UDC 674.81:662.638 ***Assoc. prof. S.V. Gayda – UNFU***

PRODUCTION TECHNIQUES AND PROPERTIES OF FUEL PELLETS PRODUCED FROM POST-CONSUMER WOOD

An estimation of the energy potential has been made for woody biomass – wood waste and post-consumer wood (PCW) – which amounted to 6.438 million tonnes in 2012, the share of PCW being 2.0 million tonnes. It has been substantiated that these resources, when converted info solid fuel, could enhance the energy potential from 2.703 to 3.548 million tonnes of equivalent fuel, that is by 24%. Up-to-date production techniques have been developed and existing equipment has been improved to produce fuel pellets from PCW as being high energy capacity raw material. Operating conditions of the production process have been considered and the optimal pellet composition was determined with various contents of solid and soft PCW particles from broadleaved and coniferous species, particles from composite material, ect. based on their pressing capability. Also presented here are the results of comparative analysis of properties of fuel pellets with varied PCW content for the following parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.

Keywords: post-consumer wood, biomass, classification of used wood, energy potential, pellets, production techniques, properties of fuel pellets, socio-economic efficiency.

Topicality. In view of today's tendency toward increase in the cost of conventional types of fuel, the problem of searching for alternative sources of energy, particularly for heating, has become especially pressing nowadays. The technological effectiveness of utilizing wood waste from wood-processing industry and PCW is sufficiently high at the forest and woodworking enterprises at the expense of reduced raw material cost. According to the draft of the updated "Ukraine's energy strategy up to 2030" [38, 39] and also in line with predictions made by the researchers G. Geletukha and T. Zhelezna, the share of biomass in the total energy consumption in Ukraine is likely to increase from 0.7% to 10% in 2030 (for comparison, this figure n the EU is to increase from 6.7% to 19%). In 2010 use of woody biomass (wood waste) for energy purposes in Ukraine amounted to 0.14% (including firewood – 0.34%) of the total supply of primary energy.

The EU countries have many years of experience with producing solid biofuel such as wood pellets from wood waste. At present, about one thousand enterprises can be counted in Europe producing biofuel pellets and briquettes; the demand for this kind of fuel is to increase to 80-135 million tonnes by 2020. The major producers of biofuel pellets are the USA (2 million tonnes per year), Sweden (1.7 million tonnes), Canada (1.3 million tonnes), Germany (0.9 million tonnes), Austria (0.8 million tonnes). The United Kingdom is planning to increase the consumption of biofuel pellets up to 5 million tonnes by the end of 2013, while China has an intention to produce no less than 50 million tonnes of pellets annualy.

In 2012, an estimated 810 thousand tonnes of solid fuel was produced in Ukraine, including almost 150 thousand tonnes of fuel pellets from wood waste. According to the Ukrainian Association of alternative solid fuel producers, over a hundred of companies are now in this kind of business, while the country as a whole is exploiting only about 3% of its potential in this sphere; Ukraine, however, is able to produce no less than 20 million tonnes of fuel pellets annualy. A certain amount of PCW is predicted to be used as energy resource of derivative raw material to produce fuel pellets on the basis of improved technologies and by developing alternative approaches.

Problem formulation. This paper covers the issues of generating energy from additional wood resources, in particular PCW, by way of converting this into fuel pellets. As of now, the problems of raw material and waste are sure to remain the "hottest" problems in the woodworking industry and power economy all over the world and particularly in Ukraine. At least partial solution of the latter problem is a rational and holistic approach to settle the first problem – the problem of raw material. PCW reserves are potential resources and untapped base for wood raw material whose supplies are increasing with the development of wood-processing industry and the economy as a whole.

The solution to the given problem is complicated through the existing varieties in PCW and especially because of the presence of various impurities (antipyren, antiseptic additives, insecticides, fungisides, biocides, complex compounds, etc.) which, through inadequate sorting and cleaning, may cause significant divergence from the predicted properties: calorific value, ash content, mechanical strength of fuel pellets from PCW as compared with those obtained from primary raw material, this being unacceptable from the environmental and economic standpoint.

The works by the foreign and Ukrainian researchers on this problem are mainly concerned with the use of wood processing residue without PCW involvement into production of fuel pellets. The results of their studies show that the given problem has not been solved yet, nor developed are the scientific basis or practical quidance for effective prediction of PCW fuel pellets properties.

PCW issues have been much investigated by various researchers in many countries, special attention being given to the impurities which has become a determinant factor as to PCW classification, that is its belonging to one or other category and, consequently, the way of its usage. For example, "PCW management regulations" has been adopted in Germany, in which the peculiarities of this waste management are given. In particular, this document clearly specifies the permissible concentration of chemical elements in PCW chips which can be used for energy purposes.

The production technology for fuel pellets was first proposed in 1947, this being constantly improved and changed according to the requirements of modern techniques and the peculiarities of one or other type of raw material used, in our case – the use of PCW, which motivates improvement of the production techniques.

Thus, the development of science-based technical basis, improvement of the existing technologies, upgrading of PCW processing equipment, development of adequate operating conditions and shaping practical advice supported by the results from experimental investigations concerning the production of fuel pellets from PCW with specified properties – all this presents an important and topical problem of the present time.

According to the standards for PCW adopted in Ukraine [27], nonhazardous kinds of the above kind of used wood are to be recommended for conversion into fuel pellets.

The objective of the study is to develop production techniques and improve the existing equipment for manufacturing fuel pellets from PCW; to develop a science-based, technical-and-technological, basis for effective prediction of the fuel pellets properties as well as to work out hands-on guidelines for quality assurance of PCW-produced fuel pellets.

The objective has been achieved by way of doing the following tasks:

- to carry out monitoring and make an estimation of the amount of PCW suitable for energy purpose – the production of fuel pellets;

- to substantiate ways and methods for cleaning PCW from various impurities;
- to develop production techniques, for manufacturing fuel pellets, through improvement of the existing technology: upgrading the system of automated control over the microprocessor-based autoproportioner; upgrading the blender for dry and wet chips with partial speed control of feed speed depending on the engine drive loading; upgrading the gravity segregator of chipped material and foreign materials; to install suspended magnetic strip and metal detector at the point of entry onto the vibrating screen;
- to improve tool equipment of the line for converting PCW into pellets, namely, the control system of temperature conditions for pelletizing, the control system of the chips moisture content at the entry as well as the digital moisture stabilizer at the point of exit;
- to validate experimentally the technological feasibility of obtaining fuel pellets from PCW in terms of pressability without application of a binder;
- to make a particle-size distribution analysis for chipped PCW;
- to carry out experimental investigations in order to determine qualitative characteristics of the pellets produced from softwoods and hardwoods species of PCW as well as from composite material;
- to check the influence of operating conditions of the fuel pellet production process on the controlled parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density;
- to make a comparative analysis with various PCW contents;
- to work out guidelines for practical implementation on the results obtained;
- to make an estimation of economic efficiency from the use of PCW for fuel pellets production.

The object of the study is the production process of fuel pellets from PCW by using upgraded and improved equipment.

The subject of the study is the patterns of technological parameters influence on the properties of PCW- produced fuel pellets in terms of predicting and quality assurance.

The methods of the study. Theoretical and experimental investigation were carried out with the application of a system approach involving computer engineering and software.

The methods used to perform the task:

- of mathematical statistics: to study qualitative characteristics of fuel pellets and to process the results;
- experimental methods for mechanical and thermomechanical cleaning; wood chipping; pellets manufacturing – pressing;
- mathematical modeling – for construction of mathematical model;
- methods of comparison – for the analysis of PCW- produced pellet properties and the properties of pellets produced from wood waste;
- methods of measurement: dry weight method – for measurement of moisture content; perforation method – for measurement of impurities content in the PCW, calorimetric method – for measurement of calorific value.

The means used to perform the task:

- upgrading automatic control system for pelletizing process by means of the microprocessor-based autoproportioner;
- upgrading the blender for dry and wet chips with partial control of feed speed depending on the engine-drive loading;
- upgrading the gravity segregator of chipped material and foreign materials;
- working out hands-on guidelines for manufacturing fuel pellets.

The approaches used to perform the task:

- application of methods for mechanical and thermomechanical cleaning of PCW;
- construction of the line for manufacturing fuel pellets from PCW;
- engineering study of suitability of certain categories of PCW as raw material for manufacturing fues pellets.

Underlying ideas to perform the task:

- improvement of the equipment to be used as the basis for constructing commercialized lines for manufacturing fuel pellets form PCW.
- development of the operating conditions for manufacturing fuel pellets from PCW
- improvement of the equipment for temperature conditions control system
- improvement of the control system for chip moisture content at the point of entry and of the digitat moisture stabilizer at the point of exit.
- installation of magnetic strip and metal detector at the point of entry onto the vibrating screen.

Working hypotheses used to perform the task:

- energy generation from additional wood resources in particular PCW, by way of turning them into fuel pellets;
- improvement of the production techniques and equipment for manufacturing fuel pellets from PCW;
- the application of wood flour pelletizer for experimental purpose;
- the advantages of fuel pellets: calorific value is 3,500-4,800 kcal/kg, moisture content within 8-12%, smaller volume, increased homogeneity of the component particles, which makes the pellets more convenient in handling and storing, also the use of pellets for heating makes it possible to apply automated systems of fuel feed.

The study of energy potential of woody biomass (wood waste and PCW).

The determination of energy potential for wood biomass was done on the basis of statistical data from the state agency of forest resources in Ukraine concerning timber harvest in 2012 (Table 1). At a level of timber harvest of 12.18 million tonnes (17.4 million m^3) in 2012 [36, 40], the volume of technically available logging residue (an average of 50% of the total wood residue quantities) amounted to 1.072 million tonnes (0.229 million tonnes of equivalent fuel), while the amount of by-products and residue from wood processing industry made up 3.362 million tonnes (1.544 tonnes of equivalent fuel) .

The total amount of green firewood (with moisture content of 45-50%) amounted to 17% of harvested volume that is 2.071 million tonnes with the energy potential being 0.523 million tonnes at the given moisture content level.

It has been found that a certain amount of PCW waste in which the share of wood amounts to over 50% – become available in Ukraine each year. Taking into account that the level of wood consumption is dependent on export-import, which compensate each other in the total balance of raw materials, the level of available PCW was calculated as 13% of the total harvested volume (a generally recognized way of calculation in the EU countries), which made up 1.58 million tonnes in 2012. In addition, an average of 50 to 60 million tonnes of solid residential waste (SRW) is available in Ukraine each year, in which the share of PCW amounts to 2 to 4%. According to the data from the ministry of regional development, housing construction, residential and public utility services, about 14 million tonnes of SRW was available in 2012, of which 0.42 million tonnes (3%) was PCW.

Thus, 2 million tonnes of PCW was available in Ukraine in 2012, with energy potential amounting to 0.936 million tonnes of equivalent fuel (27.442 PJ or 7.623 billion kWh). On turning the PCW, that was available in 2012, into fuel (with the following distribution: chips-50%, fuel pellets – 25%, fuel briquettes – 25%) it would be possible to increase the energy potential to 1.024 million tonnes of equivalent fuel, that is by 9%.

With the energy potential (excluding firewood), obtained in 2012, of 6.438 million tonnes (2.703 million tonnes of equivalent fuel or 79.4 PJ, or 22.056 billion kWh) it is possible to enhance this potential by converting the given resources into energy kinds of fuel. The resulted calculations show that the increase is likely to amount to 24%, this means that the energy value will rise to make up: 3.548 million tonnes of equivalent fuel or 104.00 PJ, or 28.889 billion kWh. With the annual power output of 198 billion kWh in 2012 in Ukraine, this would amount to 14.6% or 19.2% of an amount consumption.

Table 1. The energy potential of waste wood and used wood in Ukraine in 2012

Wood biomass and biofuels	W-%	Net Calorific Value, kkal/kg	The coefficients			Biomass - waste			Logging wood, million tons	Energy potential / year		
			t f. / t f.e.	MJ/kg	kWh	%	K	%		million t f.e.	PJ	billion kWh
Estimated numbers		7000	1	29.31	8.14	100.00			12.18			
Logging residues:												
Waste logging	60	1170	0.17	4.90	1.36	6.00	0.6	3.60	0.438	0.073	2.148	0.597
Green chips	60	1200	0.17	5.02	1.40	4.00	0.5	2.00	0.244	0.042	1.224	0.340
Chips of stumps and roots	40	2050	0.29	8.58	2.38	8.00	0.4	3.20	0.390	0.114	3.346	0.929
Total						**18.00**		**8.80**	**1.072**	**0.229**	**6.718**	**1.866**
By-products and residues WPI:												
Cutter chips (5-50 mm)	45	1950	0.28	8.16	2.27	18.00	0.1	1.80	0.219	0.061	1.790	0.497
By-products and residues						47.00						
• Furniture residues	20	3600	0.51	15.07	4.19	31.30	0.62	19.40	2.364	1.216	35.629	9.897
• Construction residues	45	2120	0.30	8.88	2.47	6.30	0.42	2.60	0.322	0.098	2.861	0.795
• Pulpwood residues	40	2370	0.34	9.92	2.76	6.30	0.33	2.10	0.253	0.086	2.513	0.698
• Plywood residues	30	2870	0.41	12.02	3.34	3.10	0.54	1.70	0.204	0.084	2.450	0.681
Total						**65.00**		**27.60**	**3.362**	**1.544**	**45.243**	**12.567**
Total by-products and residues						**83.00**		**36.41**	**4.434**	**1.773**	**51.961**	**14.433**
Firewood:												
Forest firewood (25-3000 mm)	50	1620	0.23	6.78	1.88	12.00	1	12.00	1.462	0.338	9.914	2.754
Smallwood (50-500 mm)	45	2120	0.30	8.88	2.47	5.00	1	5.00	0.609	0.184	5.406	1.502
Total						**17.00**		**17.00**	**2.071**	**0.523**	**15.320**	**4.255**
Total forest biomass						**100.00**		**53.40**	**6.505**	**2.295**	**67.281**	**18.689**
Used wood (RW, PCW):						Mio.t						
Commerce (package)	15	3850	0.55	16.12	4.48	0.301	0.15	15.00	0.301	0.165	4.847	1.346
Construction waste	18	3700	0.53	15.49	4.30	0.461	0.23	23.00	0.461	0.244	7.142	1.984
Wood-processing industry	20	3600	0.51	15.07	4.19	0.120	0.06	6.00	0.120	0.062	1.813	0.504
Furniture	10	4100	0.59	17.17	4.77	0.261	0.13	13.00	0.261	0.153	4.473	1.242
Municipal waste	40	2370	0.34	9.92	2.76	0.341	0.17	17.00	0.341	0.115	3.381	0.939
Solid domestic waste	35	2600	0.37	10.89	3.02	0.421	0.21	21.00	0.421	0.156	4.582	1.273
Other	30	2870	0.41	12.02	3.34	0.100	0.05	5.00	0.100	0.041	1.204	0.335
Total used wood mixtures	25	3280	0.47	13.73	3.81	**2.004**		**100.0**	**2.004**	**0.936**	**27.442**	**7.623**
Total waste									**6.438**	**2.709**	**79.403**	**22.056**
Wood fuels:												
Wood chips used wood	22	3250	0.46	13.61	3.78			50.00	1.002	0.465	13.637	3.788
Wood chips (5-50 mm)	30	3000	0.43	12.56	3.49			8.80	1.072	0.459	13.464	3.740
Log wood (200-2000 mm)	20	3520	0.50	14.74	4.09			4.00	0.487	0.245	7.181	1.995
Firewood (150-1000 mm)	20	3600	0.51	15.07	4.19			8.00	0.974	0.501	14.688	4.080
Chunkwood (50-150 mm)	18	3700	0.53	15.49	4.30			5.00	0.609	0.322	9.435	2.621
Wood pellet from virgin wood	7	4500	0.64	18.84	5.23							
Wood pellet from waste wood	9	4300	0.61	18.00	5.00			27.61	3.362	2.065	60.537	16.815
Wood pellet from used wood	8	4100	0.59	17.17	4.77			25.00	0.501	0.293	8.602	2.389
Wood briquette from virgin wood	10	3800	0.54	15.91	4.42							
Wood briquette from waste wood	15	3650	0.52	15.28	4.25							
Wood briquette from used wood	12	3700	0.53	15.49	4.30			25.00	0.501	0.265	7.763	2.156
Char	8	7430	1.06	31.11	8.64							
Energy potential of used wood		3850	0.55	16.12	4.48				**2.004**	**1.024**	**30.00**	**8.334**
Potential exluding firewood									**6.438**	**3.548**	**104.00**	**28.889**
Total energy potential		3700	0.53	15.49	4.30				**8.509**	**4.616**	**135.31**	**37.584**

Sources of waste wood – used wood (recovered wood, PCW).

A number of studies carried out previously have shown that waste wood arises from several different waste streams and can be categorized into different waste streams. It is important to try and categorize wood waste as it arises from a wide variety of sources and, therefore, the amount of contaminants it contains varies also.

Approximately 2.0-2.8 million tonnes of waste wood are generated each year by construction, demolition, commercial and industrial sectors in Ukraine (Table 2). Waste wood can, therefore, be categorized as coming from the following waste streams:

- Municipal waste stream;
- Commercial and Demolition waste stream;
- Commercial and Industry waste stream.

Table 2. Sustainable potential of post-consumer wood in Ukraine[26-33]

Origin and source	Potential amount used wood (recovered wood, PCW)					
	2010		2011		2012	
	%	Mio. t	%	Mio. t	%	Mio. t
Commerce (package)	13.00	0.363	12.00	0.288	15.00	0.301
Construction waste	18.00	0.503	22.00	0.527	23.00	0.461
Wood-processing industry	7.00	0.196	6.00	0.144	6.00	0.120
Furniture	12.00	0.335	12.00	0.288	13.00	0.261
Municipal waste	16.00	0.447	16.00	0.383	17.00	0.341
Solid domestic waste (SDW)	27.00	0.755	24.00	0.575	21.00	0.421
Other	7.00	0.196	8.00	0.192	5.00	0.100
Total used wood mixtures	**100.00**	**2.795**	**100.00**	**2.396**	**100.0**	**2.004**
Estimated numbers						
Uses of wooden resours (UWR)	15	13.600	15	12.140	13	12.180
Solid domestic waste (SDW)	6	12.583	4.5	12.778	3	14.033

Municipal waste. Municipal waste wood (used wood) consists of disposal by households e.g. furniture (0.261 million tonnes), fencing, decking, wood cuts from DIY, arboriculture arisings and wood packaging e.g. pallets. The two main categories of waste wood collected are from civic amenity sites and packaging suppliers. It is normal practice for Local Authorities to provide skips at civic amenity sites for the public to leave their municipal wood waste which is then collected by waste handlers such as premier waste where it is then taken to recycling facilities or disposed to landfill depending on its quality.

The waste wood is usually collected through the following:

- Civic amenity sites (CA sites or Household Waste Recycling Centres)
- Kerbside collection of household waste
- Special collections by council (bulky waste)

In the past, sorting and segregating wood waste was difficult to do due to the fact that the municipal waste stream contains mixed waste varying in its nature and composition. In recent years Local Authorities have improved the recycling facilities offering separate skips for wood waste such as pallets etc. The figures reveal that in 2012 (Table 2), 0.341 million tonnes of municipal waste and 0.1 million tonnes of non-household waste were potentially evaluated (potential amount), however these figures are not entirely accurate nor do they give recycled waste wood figures.

There is no individual figure for the recycling rates of waste wood, therefore, it is included in the ‘Other’ or the ‘Co-mingled’ category which could include waste such as electrical goods and hence not giving a true representation.

Due to these gaps of information further research needs to be carried out in order to find out how much of the ‘Other’ and ‘Co-mingled’ municipal waste sent for recycling was wood.

Construction waste. It is estimated that 0.461 million tonnes of waste wood (used wood) arises from the construction industry every year in Ukraine. The potential of the used packaging for 2012 totalled 0.301 million tonnes.

The construction and demolition waste stream is usually classed as one category; however, it produces different waste streams such as:

- Construction – Includes off-cuts from structural timbers, timber packaging, scaffolding, cladding etc.
- Demolition – Used structural timber, floorboards, joists, doors and frames etc.

These different waste streams cause a number of problems because it makes hard for the recycling industry to segregate the wood waste into different categories and, therefore, separate wood containing contaminants. In order to tackle the issue of mixed waste streams and sorting difficulties, the Government have introduced a new requirement called "Procedure of Register of the origin, processing, and utilization of waste" – the Resolution of the Cabinet of Ministers of Ukraine of August 31, 1998, No. 1360.

This demonstrates that greater support and recycling facilities are needed for smaller businesses to efficiently recover and re-use wood waste from construction sites. There seems to be a need for small sorting and segregation sites to which smaller industries could off load their waste so that the sorting process was carried out for them. This may be a practical solution to help reduce the amount of wood ending up in landfill sites as well as reducing charges from Landfill Tax. However, the problem of unidentified contaminants that may be present on the waste wood would still need to be addressed.

Wood-processing industry. Some of the main sources of wood waste that come from this sector include:

- Furniture manufacture;
- Wood waste during manufacture of packaging;
- Wood waste from wooden packaging

A large proportion of waste wood under this category is likely to be wood packaging such as wood pallets producing the highest grade of waste wood. Most of this waste coves from wood processing enterprises. The volume of wood waste (PCW waste) that can be processed outside the enterprise amounted to 0.120 million tonnes in 2012.

The analysis of European standards. Over the past decade there has been a substantial increase in the amount of biomass being used for energy in Europe [1]. As trade between countries becomes more widespread, it is necessary to create international standards to facilitate buying and selling biomass fuels. Solid biofuel is a wide field and includes woody biomass (chips, hogfuel, firewood, wood pellets, briquettes). Demolition timber is considered a hazardous waste and is not included in the solid biofuel category. The main standards in the area of biomass fuels are the EN 14961 series [4-9].

Under this code six European standards are already printed, and thus available, in all the EU countries through their National Standardisation Bodies. These documents are, at the moment, the unique European Standards dealing with solid biofuel specifications, and, even if they refer to biofuels for non industrial use (as stated in their titles), they could also be used as a reference for industrial uses while waiting for more specific standards (EN ISO 17225) [24, 25].

An overview of these standards is given in the box below:

- European Standard EN 14961-1:2010 (EN ISO 17225-1:2012) determines the fuel quality classes and specifications for solid biofuels originating from the following sources: a) products from agriculture and forestry; b) vegetable waste from agriculture and forestry; c) vegetable waste from the food processing industry; d) wood waste, with the exception of wood waste which can contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coating, and which includes in particular such wood waste originated from construction and demolition waste; e) fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and heat generated is recovered; f) cork waste.

- European standard EN 14961-2:2011 determines the fuel quality classes and specifications of wood pellets for non-industrial use. European standard EN ISO 17225-2:2012 determines the fuel quality classes and specifications of wood pellets that are sold to be used as fuel in domestic pellet stoves and pellet boilers as well as industrial heating systems. They can also be used for other applications such as horse bedding and pellet grill fuel. This European standards covers only wood pellets produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-3:2011 determines the fuel quality classes and specifications of wood briquettes for non-industrial use. This European standard covers only wood briquettes produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-4:2011 determines the fuel quality classes and specifications for non-industrial wood chips. This European standard covers only wood chip produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-5:2011 determines the fuel quality classes and specifications for firewood for non-industrial use. This European standard covers only firewood produced from the following raw material: Whole trees without roots; Chemically untreated wood residues; Stem wood; Logging residues (thick branches, tops, etc.).
- European Standard EN 14961-6:2012 determines the fuel quality classes and specifications of non woody pellets for non-industrial use. This European Standard covers only non-woody pellets produced from herbaceous biomass, fruit biomass and their blends and mixtures. Herbaceous biomass is from plants that have a non-woody stem and which die back at the end of the growing season. It includes grains or seeds crops from food processing industry and their by-products such as cereals. Blends are intentionally mixed biofuels, whereas mixtures are unintentionally mixed biofuels.

EN 14961-1 is a very general standard that explains how to classify the biomass to be used for energy purposes. Based on this classification, developed and detailed category added is the used wood as a possible resource for the production of solid fuel. (Table 3).

Table 3. Classification of woody biomass for fuel pellets [4, 24, 29]

№	Sub-categories	Code	Group origin	Sub-code	Sub-group source
1.1	Forest plantation and other virgin wood	1.1.1	Whole trees without roots	1.1.1.1	Broadleaf
				1.1.1.2	Coniferous
				1.1.1.3	Short rotation coppice
				1.1.1.4	Bushes
				1.1.1.5	Blends and mixtures
		1.1.2	Whole trees with roots	1.1.2.1	Broadleaf
				1.1.2.2	Coniferous
				1.1.2.3	Short rotation coppice
				1.1.2.4	Bushes
				1.1.2.5	Blends and mixtures
		1.1.3	Stemwood	1.1.3.1	Broadleaf
				1.1.3.2	Coniferous
				1.1.3.3	Blends and mixtures
		1.1.4	Logging residues	1.1.4.1	Fresh/green, broadleaf (including leaves)
				1.1.4.2	Fresh/Green, Coniferous, (including needles)
				1.1.4.3	Stored, Broadleaf

				1.1.4.4	Stored, Coniferous
				1.1.4.5	Blends and mixtures
		1.1.5	Stumps/roots	1.1.5.1	Broadleaf
				1.1.5.2	Coniferous
				1.1.5.3	Short rotation coppice
				1.1.5.4	Bushes
				1.1.5.5	Blends and mixtures
		1.1.6	Bark (from forestry operations)		
		1.1.7	Segregated wood from gardens, parks, roadside maintenance, vineyards and fruit orchards		
		1.1.8	Blends and mixtures		
1.2	Byproducts and residues from wood processing industry	1.2.1	Chemically untreated wood residues	1.2.1.1	Without bark, Broadleaf
				1.2.1.2	Without bark, Coniferous
				1.2.1.3	With bark, Broadleaf
				1.2.1.4	With bark, Coniferous
				1.2.1.5	Bark (from industry operations)
		1.2.2	Chemically treated wood residues, fibers and wood constituents	1.2.2.1	Without bark
				1.2.2.2	With bark
				1.2.2.3	Bark (from industry operations)
				1.2.2.4	Fibers and wood constituents
		1.2.3	Blends and mixtures		
1.3	**Used wood (recovered wood, post-consumer wood)**	1.3.1	Chemically untreated wood	1.3.1.1	Without bark
				1.3.1.2	With bark
				1.3.1.3	Bark
		1.3.2	Chemically treated wood	1.3.2.1	Without bark
				1.3.2.2	With bark
				1.3.2.3	Bark
		1.3.3	Blends and mixtures	1.3.3.1	Wood-based panel (particleboards, MDF, OSB, plywood and other composite materials)
				1.3.3.2	Packaging
				1.3.3.3	Waste wood from the construction industry
				1.3.3.4	Furniture, with no halogenated organic compounds in the coating
				1.3.3.5	Municipal waste wood
				1.3.3.6	Solid domestic waste wood
				1.3.3.7	Other blends and mixtures
1.4	Blends and mixtures.	1.4.1	Blends		
		1.4.2	Mixtures		

Following this general part, the most relevant standards for larger heating applications in the EN 14961 series are part 2 (wood pellet) and part 4 (wood chips).

EN 14961-2 defines the main parameters that should be considered for stating the quality of wood pellet and for each of them typical values for three quality classes (A1, A2 and B) are specified.

Class A1 and A2 represents pellets from virgin wood or chemically untreated wood residues. They differ mainly for the ash content, while class B allows chemically treated industrial wood byproducts and residues, and used wood.

A note: the detailed research and practical recommendations to be written about class B since not all the national legislations in EU allow the use of treated wood, thus the standard contain deviations according with the situation in Ukraine.

The same approach is adopted by EN 14961-4 on wood chips that defines 4 classes (A1, A2, B1, B2). Class A1 and A2 represent wood chips from virgin wood or chemically untreated wood residues, in this case with different ash and moisture contents. Class B1 and B2 extend the source of biomass to include (B2) chemically treated industrial wood by-products and residues and used wood.

All the quoted standards define a list of parameters to be used for stating the quality of each biofuel, and for each parameter a set of values is defined. The main parameters to be considered for non-industrial pellets and woodchips are listed in Table 4.

Table 4. Key parameters for non-industrial pellets and woodchips according to EN 14961-2 (EN ISO 17225-2:2012) **and EN 14961-4** (EN ISO 17225-4:2012)

Parameter	Meaning	Notes for Pellet	Notes for Wood Chip
Origin and source	It has to be clearly stated according with the different sources allowed by each standards.		
Diameter, D; Dimension	It is a physical value that could influence the plant/appliance feeding system.	For pellet diameter could vary from 6 to 8 mm ± 1 mm. A higher diameter could affect the correct functioning of the stove.	The dimension is important for the appliance feeding systems; it also could lead to bridging phenomena in the bulk storage
Moisture, M	This parameter mainly affect the energy content and the storage. Moreover it is often used to define the contractual price of the biofuel.	It has to be lower than 10% since an higher content could scale and damage the pellet.	It is on of the key parameter for the chips. For class A moisture could vary up to 35 %.
Ash, A	Ashes are the mineral residues remaining after a complete combustion. Their amount has to be as low as possible. An high value means bad quality of biomass or a bad management during the production of the biofuel. An high ash content leads to a more frequent maintenance of the plant/appliance/boiler (removing of ashes in the combustion chamber or cleaning of the glasses).	High quality pellet (A1) shall have an ash content lower than 0,7%. A2 class allows a higher (up to 1,5%) ash content, while B admits and ash content up to 3%.	Ash content for wood chips is approached in a similar way as for the pellet.
Mechanical durability, DU	It represents the capability of pellets to resist to crumble and break down to sawdust. It is one of the main requirements for pellet since affects its storability and integrity especially if pellet is subjected to several handling steps	It has to be the highest, more than 97,5%	Not relevant
Fines at factory gate, F	It represents the percentage of sawdust in the package. Sawdust can't be handled by the feeding systems of pellet appliances.	It has to be the lowest; no more that 1% is allowed.	Not relevant
Additives	Additives are materials which should improve the efficiency of pellet production. Pellet producers generally use starch, corn or potato flour, vegetable oil.	Type and amount have to be clearly stated. In any case a maximum amount of 2% is allowed.	Not relevant
Net Calorific Value, Q	It represents the energy content of the biofuel and is strongly connected with moisture content. Attention has to be paid for the unit used to declare this parameter. A typical mistake is to declare the gross value instead of the net, giving an overestimation of the fuel energy content.	An high calorific value could mean that pellet is made by other material than wood (plastics, glues, etc.)	
Bulk Density, BD	It is a key parameter that allows to calculate "quantities". It represents the weight (mass) of the bulk for unit volume.	It has to be higher than 600 kg/m^3	It has to be higher than 150-200 kg/m^3
N, S, Cl, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn	Chemical compounds/elements have to be considered indicators of possible contaminants of the original biomass. For this reason higher contents than expected can indicate a pollution (voluntary or involuntary) of the raw material.		

In order to give an overview of the approach used by this EN, in Table 5 an excerpt from of EN 14961-2 is shown.

The size distribution of wood chips is somewhat complicated, which is why the size requirements for the different classes are given in Table 6, while the full requirements for wood chips are given in Table 7.

Table 5. Specification of wood pellets for non-industrial use according to EN 14961-2 [5]

Parameter	Analysis method	Unit	Normative		
			A1	A2	B
Origin and source	EN 14961-1		1.1.3 1.2.1	1.1.1; 1.1.3 1.1.4; 1.1.6 1.2.1; 1.3.1	1.1 1.2 1.3
Diameter, D; Length, L	EN 16127	mm	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40
Moisture, M	EN 14774-1 EN 14774-2	as received, w-% wet basis (wb)	M10≤10	M10≤10	M10≤10
Ash, A	EN 14775	w-% dry	A0.7≤0.7	A1.5≤1.5	A3.0≤3.0
Mechanical Durability, DU	EN 15210-1	as received (a.r.), w-%	DU97.5≤97.5	DU97.5≤97.5	DU96.5≤96.5
Fines at factory gate, F	EN 15149-1	w-% a.r.	F1.0≤1,0	F1.0≤1,0	F1.0≤1,0
Net Calorific Value, Q	EN 14918	a.r. , MJ/kg or kWh/kg	Q16.5: 16.5≤Q≤19 Q4.6: 4.6≤Q≤5.3	Q16.3: 16.3≤Q≤19 Q4.5: 4.5≤Q≤5.3	Q16.0: 16.0≤Q≤19 Q4.4: 4.4≤Q≤5.3
Bulk Density, BD	EN 15103	kg/m3	BD600≥600	BD600≥600	BD600≥600
Additives		w-% dry	≤2w-% Types and amount to be stated		
Nitrogen, N	EN 15104	w-% dry	N0.3≤0.3	N0.5≤0.5	N1.0≤1.0
Sulphur, S	EN 15289	w-% dry	S0.03≤0.03	S0.03≤0.03	S0.04≤0.04
Chlorine, Cl	EN 15289	w-% dry	Cl0.02≤0.02	Cl0.02≤0.02	Cl0.03≤0.03
Arsenic, As	EN 15297	mg/kg dry	≤1	≤1	≤1
Cadmium, Cd	EN 15297	mg/kg dry	≤0.5	≤0.5	≤0.5
Chromium, Cr	EN 15297	mg/kg dry	≤10	≤10	≤10
Copper, Cu	EN 15297	mg/kg dry	≤10	≤10	≤10
Lead, Pb	EN 15297	mg/kg dry	≤10	≤10	≤10
Mercury, Hg	EN 15297	mg/kg dry	≤0.1	≤0.1	≤0.1
Nickel, Ni	EN 15297	mg/kg dry	≤10	≤10	≤10
Zinc, Zn	EN 15297	mg/kg dry	≤100	≤100	≤100

Table 6. Product standard for wood chips EN 14961-4 – Particle size (P) [7]

Luokka	Minimum 75 w-% (main fraction), mm	Fine fraction, w-%, < 3,15 mm	Coarse fraction, w-% maximum length of particle, mm
P16A	3.15 ≤ P ≤ 16 mm	≤ 12 %	≤ 3% > 16 mm, and all < 31.5 mm The cross sectional area for oversized particles < 1 cm^2
P16B	3.15 ≤ P ≤ 16 mm	≤ 12 %	≤ 3% > 45 mm, and all< 120 mm The cross sectional area for oversized particles < 1 cm^2
P31,5	8 ≤ P ≤ 31,5 mm	≤ 8 %	≤ 6% > 45 mm, and all < 120 mm The cross sectional area for oversized particles < 2 cm^2
P45A	8 ≤ P ≤ 45 mm	≤ 8 %	≤ 6% > 6 mm and maximum 3.5 % > 100 mm, The cross sectional area for oversized particles < 5 cm^2

The numerical values (P-class) for dimension refer to the particle sizes (at least 75 w-%) passing through the mentioned round hole sieve size (EN 15149-1).

Table 7. Some qualitative values for non-industrial wood chip according to EN 14961-4 [7]

Property class	Analysis method	Unit	Normative			
			A1	A2	B1	B2
Origin and source	EN 14961-1		1.1.1; 1.1.3 1.2.1; 1.1.4.3	1.1.1; 1.1.3 1.2.1; 1.1.4.1	1.1 1.2.1	1.2 1.3
Particle size, P	EN 15149-1 EN 15149-2	mm	To be selected from Table 1			
Moisture, M	EN 14774-1 EN 14774-2	as received, (a.r.), w-%	M10≤10 M25≤25	M35≤35	To be specified	
Ash, A	EN 14775	w-% dry	A1.0≤1,0	A1.5≤1.5	A3.0≤3.0	
Net Calorific Value, Q	EN 14918	a.r. , MJ/kg or kWh/kg	Q13.0≥13,0 or Q3.6≥3,6	Q11.0≥11,0 or Q3.1≥3,1	To be specified	
Bulk Density, BD	EN 15103	kg/loose m3	BD150≥150 BD200≥200	BD150≥150 BD200≥200	To be specified	
Nitrogen, N	EN 15104	w-% dry	N0.3≤0.3	N0.5≤0.5	N1.0≤1.0	
Sulphur, S	EN 15289	w-% dry	S0.03≤0.03	S0.03≤0.03	S0.1≤0.1	
Chlorine, Cl	EN 15289	w-% dry	Cl0.02≤0.02	Cl0.02≤0.02	Cl0.05≤0.05	
Arsenic, As	EN 15297	mg/kg dry	≤1	≤1	≤1	
Cadmium, Cd	EN 15297	mg/kg dry	≤0.5	≤0.5	≤02,0	
Chromium, Cr	EN 15297	mg/kg dry	≤10	≤10	≤10	
Copper, Cu	EN 15297	mg/kg dry	≤10	≤10	≤10	
Lead, Pb	EN 15297	mg/kg dry	≤10	≤10	≤10	
Mercury, Hg	EN 15297	mg/kg dry	≤0.1	≤0.1	≤0.1	
Nickel, Ni	EN 15297	mg/kg dry	≤10	≤10	≤10	
Zinc, Zn	EN 15297	mg/kg dry	≤100	≤100	≤100	

Analysis data collections showed how inadequate is the current status of pellet standardization and certification in Europe. The existing national standards with individual quality requirements were not accepted by all stakeholders and did not spread within Europe. In most European countries, pellet quality standards are not used at all. Thus, national standards may have contributed to the development of single national pellet markets but the absence of common European standardisation was an important barrier to further development of the European pellet market in general and to increased international pellet trade in particular.

It can be expected that this situation will improve greatly with the implementation of new European standards for solid biofuels, including pellets.

The experience gained during the analysis was that standards alone are not sufficient to promote European pellet markets. The diversity of raw materials, the rapidly increasing number of producers and the critical importance of pellet quality for consumer satisfaction and, therefore, for market growth in general make the reinforcement and compliance with standards necessary. In order to reinforce the compliance with quality standards, internal quality management needs to be accompanied by regular, external and unannounced control at the production sites. The end-consumer needs a reliable and recognisable quality label facilitating buying decisions. Quality labels also are an important marketing instrument for pellet producers. Finally, quality labels are used by pellet appliance manufacturers in warranty conditions that exclude the use of pellets without quality label.

All this can be provided by quality certification schemes that award a reliable and recognizable quality label following regular external controls. Therefore, already in

2013, recommended EN 14961, EN ISO 17225 and EN 15234 as a basis for a pan-European certification system could be used across Europe and facilitate international pellet trade and market development.

This recommendation will be followed by Ukrainian certification bodies who decided to adapt their systems to the framework set by European standards.

The testing methods for in-house sampling and quality assurance.

The test of wood pellets for in-house sampling and quality control (physical and mechanical properties) was conducted immediately after their manufacture. Wood pellets have been tested in accordance with European standards biofuel soil (Table 8).

Table 8. The methodology for testing experimental fuel pellets [10-23]

Parameter	Analysis method	Unit	Repeatability limit
Origin and source	EN 14961-1:2010 EN 17225-1:2012		1.2. Byproducts and residues from wood processing industry
			1.3. Used wood (recovered wood, post-consumer wood)
Sampling	EN 14778:2011	kg ar	individual samples
Sample preparation	EN 14780:2011	kg ar	individual samples
Diameter, D;	EN 16127:2012	mm	D06, 6±1
Length, L	EN 16127:2012	mm	3,15≤L≤40 (95 w-%)
Moisture, M as received (ar)	EN 14774-1:2009 EN 14774-2:2009	w-% ar	< 0.2 % absolute (M≤10%)
Ash, A of dry basis (db) (550 ºC)	EN 14775:2009	w-% db	<2 % of the mean result (A≥10 %) < 0.2 % absolute (A<10 %)
Mechanical Durability, DU	EN 15210-1:2009	w-% ar	<0.4 % absolute (DU≥97.5 %) < 2 % absolute (DU<97.5 %)
Fines at factory gate, F	EN 15149-1:2010	w-% ar	< 0.2 % absolute (F≤1.0 %)
Net Calorific Value, Q	EN 14918:2010	MJ/kg ar	< 120 J/g (Q ≥16.0 MJ/kg)
Bulk Density, BD	EN 15103:2010	kg/m^3	<4 % (BD ≥ 300 kg/m^3) <6 % (BD < 300 kg/m^3)

Sampling [2, 3]. The sampling and sample portioning for the tests in the scope of external inspections are conducted according to EN 14778:2011 (Sampling) and EN 14780:2011 (Sample preparation). As the procedures listed in the respective standards are very extensive, a simplified procedure for drawing samples for in-house analyses will be described in the following. Single samples (increments) should, if possible, be taken from the moving material, as the quality of the total batch can be best indicated in this way. During sample partitioning for the individual analyses, it should also be made certain that the respective subsamples represent the quality of the total batch. The subsamples should be taken with a small sampling scoop in order to assure that the fine material quantity can also be tested.

- ***From moving material.*** At least five individual samples, with a mass of 4 kg per sample, will be taken. Attention should be paid that at least 20 kg of material passes through the sampling point between the individual sampling procedures. The individual samples will be thoroughly mixed and compiled into a cone. This will subsequently be pressed flat and divided into four equally large parts by a vertically inserted scoop. The process is to be so often repeated until the required sample size for the respective test is approximately achieved. Care must be taken to assure that all subsamples possess the same consistency.
- ***From static material.*** At least five individual samples, with a mass of 4 kg per sample, are to be taken at different points of the filling process. With bagged wood pellets, an individual sample will be respectively taken from one bag. The individual samples will be thoroughly mixed and compiled into a cone. This will subsequently be pressed flat and divided into four equally large parts by a vertically inserted scoop. The process is to be so often repeated until the required sample size for the respec-

tive test is approximately achieved. Care must be taken to assure that all subsamples possess the same consistency.

Mechanical durability (DU). The subsequent determination of the mechanical durability is done on the basis of EN 15210-1:2009. Firstly, two subsamples drawn from the sieved pellets, with a mass of (500±10) g respectively, are formed and weighed. They are successively put into the testing chamber of the measuring device, which rotates at (50±2) revolutions per minute. After 500 rotations, the drum is to be emptied and the fine material is to be sieved again. Afterwards, the remaining wood pellets will be weighed and the mechanical durability will be determined using the following formula (1):

$$DU = (m_A/m_E) \times 100, \quad (1)$$

where: DU – mechanical durability, w-%; m_A – mass of the sieved wood pellets after the handling process, g; m_E – mass of the pre-sieved wood pellets before the handling process, g.

An average value will be generated from the results of the testing of both subsamples. On account of the expected divergence from the determination, a divergence of the mean value from the threshold value of an abrasion of up to 0.2 % must be accepted.

Fine material amount (F). The mass will be determined by taking a sample of approximately 1.2 kg. Subsequently, the amount of fine material will be separated with a 3.15 mm – Certification of Wood Pellets for Heating Purposes 31 sieve according to ISO 3310-1. When the sieving is done manually according to EN 15210-1:2009, care must be taken that, on one hand, all fine particles are separated and, on the other hand, that no new fine material forms through the mechanical strain. This can be achieved by shaking the sample in 5 to 10 circular motions using a sieve with a diameter of 40 cm. Then the sieved particles will be weighed. The fine material amount (F, w-%) will be calculated as follows (2):

$$F = (m_A/m_E) \times 100, \quad (2)$$

where: m_A – mass of the sieved particles, g; m_E – mass of the sample before sieving, g.

Bulk Density (BD). The determination of the bulk density follows on the basis of EN 15103:2010. Wood pellets will be poured from a height of 200 to 300 mm into a measuring cylinder, with a volume of five liters and a defined diameter-height ratio, until the cylinder is full and a debris cone has formed. Subsequently, the cylinder will be dropped three times from a height of 150 mm onto a hard surface in order to consolidate the wood pellets. After excess material has been removed by striking a straight edge along the top and larger cavities have been filled, the mass of the wood pellets in the cylinder is determined.

The bulk density (BD) will be calculated using the following formula (3):

$$BD = (m_2-m_1)/V, \quad (3)$$

where: BD – bulk density, kg/m^3; m_1 – mass of the empty container, kg; m_2 – mass of the full container, kg; V – net volume of the measuring cylinder, m^3.

Afterwards, the sample material is poured out and mixed with the remaining wood pellets before the procedure is repeated. An average value will be generated from the results of both measurements.

Moisture content (M_{ar}). The determination of the moisture content follows on the basis of EN 14774-2:2009. First, the mass of the empty drying dish will be determined (accuracy: 0.1 g). Subsequently, the dish will be filled with at least 300 grams of wood pellets and re-weighed. The sample will then be dried in a drying chamber (oven) at (105 ± 2) °C until constant mass has been achieved. After the mass has been determined within 15 seconds of removing it from the drying chamber (weighing as hot), the moisture content will be calculated using the following formula (4):

$$M_{ar}=(m_2-m_3)/(m_2-m_1)\times100, \quad (4)$$

where: M_{ar} – moisture content as received, w-%; m_1 – mass of the empty drying pan, g; m_2 – mass of the drying pan and sample before drying, g; m_3 – mass of the drying pan and sample after drying, g.

Ash content (A_d). Ash content is another important test for determining wood fuel properties. Ashing temperature for wood fuel standards is a significant point of difference with coal ashing standards. EN 14775:2009 describes the method for ash content of solid biofuels. Ash, the material remaining, calculated on the basis of the dry weight of the original sample, after the sample is ignited at a specified temperature. Ash at 550± 10°C, the ash content of the sample when the ignition temperature is 550±10°C.

Carefully clean the empty crucible and ignite in a muffle furnace at 550±10°C for 60 minutes. After ignition, cool slightly and then place in a desiccator. When cooled to room temperature, weigh the ignited crucible on the analytical balance to the nearest 0.1 mg. A 1 g sample is initially ashed at 250±10°C until volatiles are burnt off slowly (to avoid losing entrained particles with fast burning) and then a heating regime is followed to finish with an ashing temperature of 550±10°C for at least 2 hours. When the specimen is completely combusted as indicated by the absence of black particles, remove the crucible from the furnace, replace the cover, and allow to cool somewhat; then place in a desiccator containing indicating grade anhydrous alumina and cool to room temperature. Weigh the crucible with ash to the nearest 0.1 mg. Repeat the ignition and weighing until the weight of the ash is constant to ±0.2 mg.

Calculate the ash content as follows (5):

$$A_d = (m_3\text{-}m_1)/(m_2\text{-}m_1) \times 100 \times (100)/(100\text{-}M_{ad}),\ \text{w-\%} \qquad (5)$$

where: m_1 – mass of empty crucible, g; m_2 – mass of crucible with breakdowns, g; m_3 – mass of crucible with ash residue, g; M_{ad} – mass shake in the moisture of analytical samples, w-%.

Report the ash content in the sample as an average of two determinations to the nearest 0.01 % when the ash content is below 10 %, or to the nearest 0.1 % if the ash content is 10 % and higher.

Determination of calorific values. The net calorific value of solid fuels for dry matter is determined in accordance with standard EN 14918:2010.

Gross calorific value is the absolute value of the specific energy of combustion, in joules, for unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under the conditions specified. The products of combustion are assumed to consist of gaseous oxygen, nitrogen, carbon dioxide and sulfur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under the conditions of the bomb reaction, and of solid ash, all at the reference temperature.

Net calorific value at constant volume is the absolute value of the specific energy of combustion, in joules, for unit mass of the biofuel burned in oxygen under conditions of constant volume and such that all the water of the reaction products remains as water vapour (in a hypothetical state at 0.1 MPa), the other products being as for the gross calorific value, all at the reference temperature.

As the third calorific value, the *net calorific value as received* can be given. This calorific value is the lowest one, as the energy used for evaporating water contained naturally in the fuel and water formed in combustion are reduced when calculating the calorific value. The calorific value is usually given as megajoules for kg fuel (MJ/kg, 1 MJ = 0.2778 kWh).

Gross calorific value. In EN 14918:2010 method about 1 g±0.1 of air-dry (equilibrium moisture content) analysis sample is burnt in high-pressure oxygen in a bomb calorimeter under specified conditions. The effective heat capacity of the calorimeter is determined in calibration experiments by combustion of certified benzoic acid under similar conditions, accounted for in the certificate. The corrected temperature rise is established from observations of temperature before, during and after the combustion reaction takes place. The duration and frequency of the temperature observations depend on the type of calorimeter used. The duration and frequency of the temperature observations depend on the type of calorimeter used. Water is added to the bomb initially to give a saturated vapour phase prior to combustion, thereby allowing all the water formed, from the hydrogen and moisture in the sample, to be regarded as liquid water. The gross calorific value is calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the biofusels) and for thermal effects from side reactions such as the formation of nitric acid. Furthermore, a correction is applied to account for the difference in energy between the aqueous sulfuric acid formed in the bomb reaction and gaseous sulfur dioxide, i.e. the required reaction product of sulfur in the biofuel.

The net calorific value at constant volume and the net calorific value at constant pressure of the biofuel are obtained by calculation from the gross calorific value at constant volume determined on the analysis sample. The calculation of the net calorific value at constant volume requires information about the moisture and hydrogen contents of the analysis sample. In principle, the calculation of the net calorific value at constant pressure also requires information about the oxygen and nitrogen contents of the sample. As the moisture content of the actual analysis sample is of interest merely in connection with the calculation to other bases, it is recommended to calculate a value for the gross calorific value at constant volume for the dry fuel, using the following equation (6):

$$q_{V,gr,d} = q_{V,gr} \times 100/(100\text{-}M_{ad}) \quad (6)$$

where: $q_{V,gr,d}$ – gross calorific value at constant volume of the dry (moisture-free) fuel, J/g; M_{ad} – moisture in the analysis sample, w-%; $q_{V,gr}$ – gross calorific value at constant volume of the fuel as analysed, J/g.

The result shall be reported to the nearest multiple of 10 J/g with unambiguous statements concerning the states constant volume, gross (liquid water), and moisture basis (e.g. dry or "as sampled").

Net calorific value. The energy of vaporization (constant volume) for water is at 25 °C is 41.53 kJ/mol. This corresponds to 206 J/g for 1% (weight) of hydrogen in the fuel sample or 13.05 J/g for 1 w-% of moisture, respectively. The net calorific value at content volume is derived from the corresponding gross calorific value according to equation (7) (EN 149186:2010).

$$q_{p,net,d} = q_{V,gr,d} - 212{,}2 \times w(H)_d - 0{,}8 \times [w(O)_d + w\,(N)_d] \quad (7)$$

where: $q_{p,net,d}$ – net calorific value for dry matter at constant pressure, MJ/kg; $q_{V,gr,d}$ – gross calorific value for dry matter, MJ/kg; $w(H)_d$ – the hydrogen content of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance), w-%; $H(O)_d$ – the oxygen content of the moisture-free biofuel, w-%; $w(N)_d$ – the nitrogen content of the moisture-free biofuel, w-%.

Net calorific value of fuel as received **(Q_{ar}).** Net calorific value as received is calculated according to equations 8. The calorific value can be either determined for that particular lot or a typical value can be used. The net calorific value (at constant pressure) as received (the moist biofuel) can be calculated on the net calorific value of the dry basis according to equation (8).

$$q_{p,net,ar} = q_{p,net,d} \times (100 - M_{ar})/100 - 0{,}02443 \times M_{ar} \quad (8)$$

where: $q_{p,net,ar}$ – net calorific value (at constant pressure) as received, MJ/kg; $q_{p,net,d}$ – net calorific value (at constant pressure) in dry matter, MJ/kg; M_{ar} – moisture content as received (total moisture), w-%; 0,02443 – the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C (MJ/kg per 1 w-% of moisture).

The results of experimental investigation. The data obtained from physical and mechanical testing of pilot PCW-containing wood pellets for moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density, the length and diameter are shown in Tables 9-14.

Table 9. The results of testing PCW-containing wood pellets for moisture content

No	Factor value in the experiment						Moisture content measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	6.90	7.10	7.00	7.20	7.10
2	100	8	0	1	-1	-1	6.20	6.40	6.40	6.10	6.50
3	0	16	0	-1	1	-1	11.80	12.00	12.20	12.10	11.60
4	100	16	0	1	1	-1	11.10	10.90	10.80	10.90	10.80
5	0	8	3	-1	-1	1	9.80	9.90	9.70	9.60	9.90
6	100	8	3	1	-1	1	8.90	9.20	9.10	9.00	8.90
7	0	16	3	-1	1	1	10.80	10.90	10.70	10.80	10.90
8	100	16	3	1	1	1	9.80	9.80	9.90	10.00	9.90

Table 10. The results of testing PCW-containing wood pellets for ash content

No	Factor value in the experiment						Ash content measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	0.21	0.26	0.25	0.27	0.24
2	100	8	0	1	-1	-1	0.36	0.38	0.35	0.39	0.34
3	0	16	0	-1	1	-1	0.26	0.29	0.31	0.28	0.29
4	100	16	0	1	1	-1	0.46	0.42	0.46	0.48	0.45
5	0	8	3	-1	-1	1	0.53	0.57	0.55	0.59	0.54
6	100	8	3	1	-1	1	0.68	0.72	0.78	0.71	0.74
7	0	16	3	-1	1	1	0.62	0.64	0.63	0.65	0.65
8	100	16	3	1	1	1	0.86	0.88	0.84	0.94	0.90

Table 11. The results of testing PCW-containing wood pellets for mechanical durability

No	Factor value in the experiment						Mechanical durability measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	98.00	97.90	98.00	98.30	98.20
2	100	8	0	1	-1	-1	96.90	97.10	97.20	97.00	97.10
3	0	16	0	-1	1	-1	95.00	94.80	95.00	95.20	95.10
4	100	16	0	1	1	-1	94.00	93.80	94.20	94.00	93.90
5	0	8	3	-1	-1	1	98.90	99.00	98.70	98.90	99.00
6	100	8	3	1	-1	1	97.80	98.10	98.20	98.20	97.90
7	0	16	3	-1	1	1	97.10	97.30	97.30	96.90	97.00
8	100	16	3	1	1	1	95.90	96.00	96.20	96.20	96.30

Table 12. The results of testing PCW-containing wood pellets for fines at factory gate

No	Factor value in the experiment						Fines at factory gate measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	0.99	0.98	0.97	0.99	0.96
2	100	8	0	1	-1	-1	0.88	0.95	0.97	0.95	0.95
3	0	16	0	-1	1	-1	0.87	0.92	0.95	0.88	0.93
4	100	16	0	1	1	-1	0.86	0.9	0.87	0.84	0.83
5	0	8	3	-1	-1	1	0.55	0.58	0.51	0.52	0.54
6	100	8	3	1	-1	1	0.48	0.53	0.49	0.49	0.46
7	0	16	3	-1	1	1	0.4	0.38	0.44	0.42	0.41
8	100	16	3	1	1	1	0.39	0.34	0.42	0.4	0.4

Table 13. The results of testing PCW-containing wood pellets for net calorific value

No	Factor value in the experiment						Net calorific value measurements, MJ/kg				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	19.21	19.20	19.32	19.28	19.08
2	100	8	0	1	-1	-1	19.10	19.11	19.16	18.92	18.95
3	0	16	0	-1	1	-1	18.14	18.15	17.96	18.12	17.98
4	100	16	0	1	1	-1	17.81	17.96	17.82	17.90	17.96
5	0	8	3	-1	-1	1	20.40	20.96	20.76	20.34	20.56
6	100	8	3	1	-1	1	20.15	19.97	19.88	20.22	20.16
7	0	16	3	-1	1	1	18.13	18.22	18.40	18.20	18.30
8	100	16	3	1	1	1	18.25	17.50	17.82	18.10	18.20

Table 14. The results of testing PCW-containing wood pellets for bulk density

No	Factor value in the experiment						Bulk density measurements, kg/m^3				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	640	642	640	643	637
2	100	8	0	1	-1	-1	628	632	629	631	633
3	0	16	0	-1	1	-1	658	657	659	662	658
4	100	16	0	1	1	-1	648	651	651	647	652
5	0	8	3	-1	-1	1	662	660	659	659	661
6	100	8	3	1	-1	1	653	652	650	654	652
7	0	16	3	-1	1	1	678	675	674	675	677
8	100	16	3	1	1	1	668	667	665	669	668

On calculating mean values and sample variances, the check on variance homogeneity in the experiments by means of Kohren G-criterion indicated that all the variances were homogeneous. By using similar procedure, the variances of reproducibility of measurements of physical and mechanical properties of wood pellets were calculated: for moisture content: $\mathbf{S_{re}}^2$ = 0.0201; for ash content: $\mathbf{S_{re}}^2$ = 0.0007; for mechanical durability: $\mathbf{S_{re}}^2$ = 0.0239; for fines at factory gate: $\mathbf{S_{re}^2}$ = 0.0007; for net calorific value: $\mathbf{S_{re}^2}$ = 0.0286; for bulk density: $\mathbf{S_{re}^2}$ = 3.3625. The root-mean-square deviation for calculated coefficients of regression equations made up: for moisture content: **S{b$_i$}** = 0.0224; for ash content: **S{b$_i$}** = 0.0041; for mechanical durability: **S{b$_i$}** = 0.02; for fines at factory gate: **S{b$_i$}** = 0.0042; for net calorific value: **S{b$_i$}** = 0.03; for bulk density: **S{b$_i$}** = 0.2899. On checking regression equations coefficients for meaningfulness and establishing their confidence intervals, the calculations showed that the regression equations coefficient are meaningful except for six ones (Tables 15-20), but we do not ignore them in consideration of system approach.

Table 15. Checking regression equation coefficients for meaningfulness, their confidence intervals for moisture content

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{tab}*S\{b_i\}$	$b_i+t_{tab}*S\{b_i\}$
b_o	9.465	0.046	Meaningful	9.419	9.511
b_1	-0.435	0.046	Meaningful	-0.481	-0.389
b_2	1.420	0.046	Meaningful	1.374	1.466
b_3	0.410	0.046	Meaningful	0.364	0.456
b_{12}	-0.060	0.046	Meaningful	-0.106	-0.014
b_{13}	0.010	0.046	No meaningful	-0.036	0.056
b_{23}	-0.945	0.046	Meaningful	-0.991	-0.899

Table 16. Checking regression equation coefficients for meaningfulness, their confidence intervals for ash content

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{tab}*S\{b_i\}$	$b_i+t_{tab}*S\{b_i\}$
b_o	0.519	0.008	Meaningful	0.511	0.528
b_1	0.088	0.008	Meaningful	0.079	0.096
b_2	0.046	0.008	Meaningful	0.038	0.055
b_3	0.182	0.008	Meaningful	0.173	0.190
b_{12}	0.016	0.008	Meaningful	0.007	0.024
b_{13}	0.016	0.008	Meaningful	0.008	0.025
b_{23}	0.014	0.008	Meaningful	0.005	0.022

Table 17. Checking regression equation coefficients for meaningfulness, their confidence intervals for mechanical durability

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{таб}*S\{b_i\}$	$b_i+t_{таб}*S\{b_i\}$
b_o	96.790	0.050	Meaningful	96.740	96.840
b_1	-0.490	0.050	Meaningful	-0.540	-0.440
b_2	-1.230	0.050	Meaningful	-1.280	-1.180
b_3	0.755	0.050	Meaningful	0.705	0.805
b_{12}	-0.020	0.050	No meaningful	-0.070	0.030
b_{13}	0.025	0.050	No meaningful	-0.025	0.075
b_{23}	0.305	0.050	Meaningful	0.255	0.355

Table 18. Checking regression equation coefficients for meaningfulness, their confidence intervals for fines at factory gate

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{таб}*S\{b_i\}$	$b_i+t_{таб}*S\{b_i\}$
b_o	0.690	0.009	Meaningful	0.681	0.698
b_1	-0.020	0.009	Meaningful	-0.028	-0.011
b_2	-0.047	0.009	Meaningful	-0.056	-0.039
b_3	-0.232	0.009	Meaningful	-0.241	-0.224
b_{12}	0.002	0.009	No meaningful	-0.006	0.011
b_{13}	0.002	0.009	No meaningful	-0.006	0.011
b_{23}	-0.010	0.009	Meaningful	-0.019	-0.002

Table 19. Checking regression equation coefficients for meaningfulness, their confidence intervals for net calorific value

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{ra6}*S\{b_i\}$	$b_i+t_{ra6}*S\{b_i\}$
b_o	18.891	0.055	Meaningful	18.837	18.946
b_1	-0.144	0.055	Meaningful	-0.199	-0.090
b_2	-0.845	0.055	Meaningful	-0.900	-0.791
b_3	0.335	0.055	Meaningful	0.280	0.389
b_{12}	0.030	0.055	No meaningful	-0.024	0.085
b_{13}	-0.057	0.055	Meaningful	-0.111	-0.002
b_{23}	-0.269	0.055	Meaningful	-0.323	-0.214

Table 20. Checking regression equation coefficients for meaningfulness, their confidence intervals for bulk density

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{ra6}*S\{b_i\}$	$b_i+t_{ra6}*S\{b_i\}$
b_o	654.400	0.591	Meaningful	653.809	654.991
b_1	-4.400	0.591	Meaningful	-4.991	-3.809
b_2	8.550	0.591	Meaningful	7.959	9.141
b_3	9.500	0.591	Meaningful	8.909	10.091
b_{12}	0.050	0.591	No meaningful	-0.541	0.641
b_{13}	0.300	0.591	No meaningful	-0.291	0.891
b_{23}	-0.850	0.591	Meaningful	-1.441	-0.259

The regression equation coefficients obtained as a result of the full-factorial plan realization possess a clean physical meaning. The coefficient $\mathbf{b_o}$ is equal to the output value and of all factors are fixed at the basic level. The sigh of the coefficient $\mathbf{b_i}$ points to the nature of corresponding factor influence: if $\mathbf{b_i>0}$, the output value tends to increase with an increase of the factor $\mathbf{X_i}$ value, and vice versa. The absolute value of the regression coefficient in the model points to the extent to which the response function is affected by the corresponding factor. The higher absolute value of the coefficient, the stronger influence on the output parameter change has the factor to which the given coefficient corresponds. Thus, the extent of the factors effect on the output values can be compared by means of linear regression model and so revealing the most important factors.

In order to evaluate the ability of the obtained models to describe output values with the same degree of accuracy as the experimental results, the mathematical models were checked for their adequacy by Fisher F-criterion by means of which the variances of adequacy $\mathbf{S_{ad}^2}$ and reproducibility $\mathbf{S_{re}^2}$ are compared.

The calculated adequacy variances for physical and mechanical properties of PCW-containing wood pellets made up: for moisture content $\mathbf{S_{ad}^2}$ = 0.009; for ash content $\mathbf{S_{ad}^2}$ = 0.0042; for mechanical durability $\mathbf{S_{ad}^2}$ = 0.009; for fines at factory gate $\mathbf{S_{ad}^2}$ = 0.0011; for net calorific value $\mathbf{S_{ad}^2}$ = 0.0043; for bulk density $\mathbf{S_{ad}^2}$ = 0.9.

The calculated values for Fisher criterion for physical and mechanical properties of PCW-containing wood pellets made up: for moisture content $\mathbf{F_{cal}}$ = 2,236; for ash content $\mathbf{F_{cal}}$ = 1,592; for mechanical durability $\mathbf{F_{cal}}$ = 2,653; for fines at factory gate $\mathbf{F_{cal}}$ = 1,549; for net calorific value $\mathbf{F_{cal}}$ = 1,5; for bulk density $\mathbf{F_{cal}}$ = 3,736.

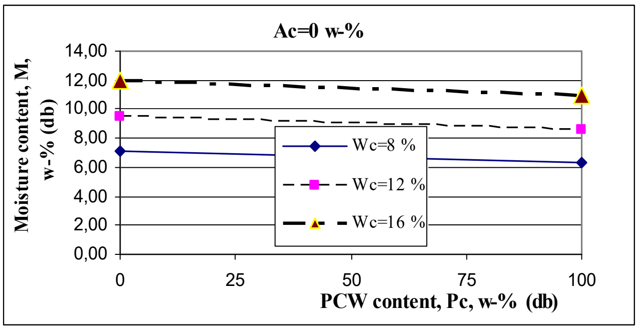
The tabulated value for Fisher criterion is equal to $\mathbf{F_{tab}}$ = ***F(7; 5) =6,1***. By comparing the calculated values for Fisher criteria with the tabulated ones, we can see that the inequality $\mathbf{F_{cal}} < \mathbf{F_{tab}}$ is accomplished for physical and mechanical properties of PCW-containing wood pellets. That is, the mathematical models obtained are considered adequate and can be used to describe objects.

Thus, the calculations done made it possible to obtain the following regression equations of the full-factorial plan with actual factor values for physical and mechanical properties.

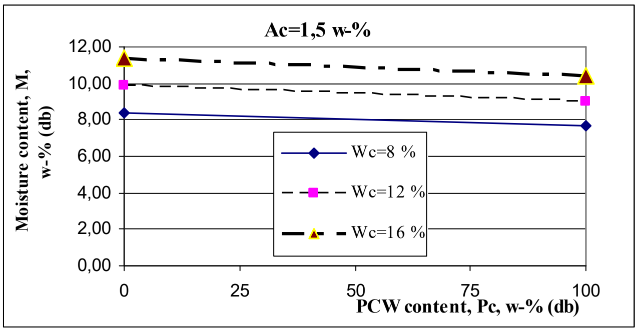
$$M = 2{,}225 - 0{,}0051Pc + 0{,}6063Wc + 2{,}157Ac - 0{,}06PcWc + 0{,}00013PcWc - 0{,}1575WcAc$$
$$A = 0{,}216 + 0{,}00048Pc + 0{,}0042Wc + 0{,}083Ac + 0{,}00008PcWc + 0{,}00022PcWc + 0{,}0023WcAc$$
$$DU = 101{,}095 - 0{,}0091Pc - 0{,}37875Wc - 0{,}1234Ac - 0{,}0001PcWc + 0{,}00033PcAc + 0{,}05083WcAc$$
$$F = 1{,}062 - 0{,}00058Pc - 0{,}0981Wc - 0{,}13583Ac + 0{,}00001PcWc + 0{,}00003PcAc - 0{,}00171WcAc$$
$$Q = 20{,}464 - 0{,}0035Pc - 0{,}1517Wc + 0{,}7985Ac + 0{,}00015PcWc - 0{,}00076PcAc - 0{,}0448WcAc$$
$$BD = 621{,}55 - 0{,}097Pc + 2{,}34Wc + 7{,}83Ac + 0{,}00025PcWc + 0{,}0004PcAc - 0{,}1417WcAc$$

The data of regression equations describe the physical and mechanical properties of PCW-containing wood pellets and allow output values to be calculated for any point of the experiment zone provided that $\mathbf{X_i = [-1;+1]}$, where $\mathbf{i = 1, k}$.

Since the influence of factors and their interaction on the response function is best analyzed graphically, six groups of diagrams were constructed by regression equations: the relationship between output value (moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density) and PCW content, chips moisture at the constant values for the additives content at the minimum, mean, and maximum levels (Fig. 1-6).



a



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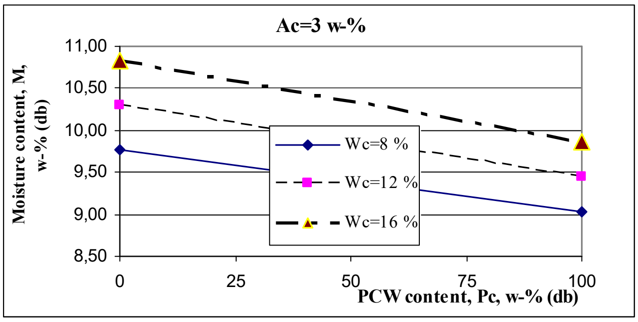


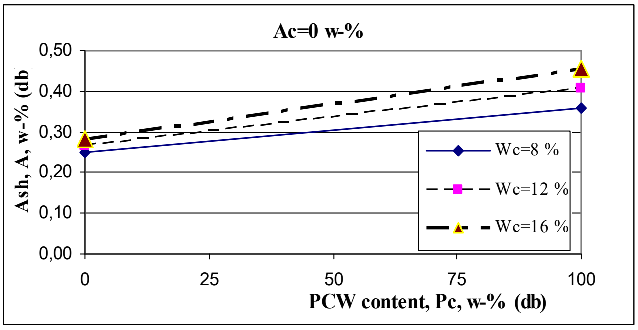
c

Fig. 1. The dependence of the <u>moisture content</u> of wood pellets on the content of PCW, chips moisture, content of additives:
a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

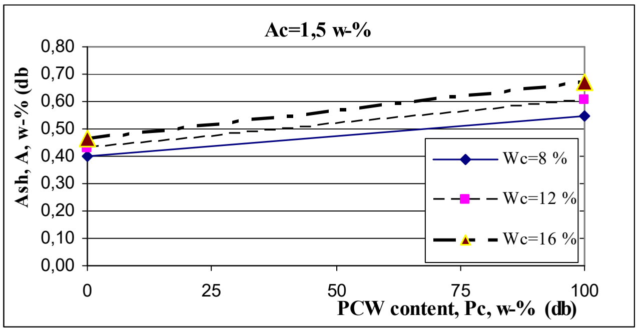
Graphical representation of the relationships obtained allows for revealing the character of variable factors influence on the properties of the resulting wood pellets, since the full-factorial plan was realized here, all the dependences have linear character. The diagrams also show that the lines do not run parallel to one another, and the angle of their slope varies as certain variable factors change. This points to the fact that the influence of factors interaction is just as significant as the influence of the individual factors.

As is easily seen from the diagrams, PCW content in fuel pellets has a linear dependence (either increases or decreases) within a 0-100% range at different additive (binder) content. In particular, at a 1.5% value for the additive content and chips moisture content prior to pressing of 12% the ash content increases from 0.43 to 0.61% (by

41.8%), while all the other tested pellet parameters decrease: the moisture content – from 9.90 to 9.03% (by 9.8%), mechanical durability – from 97.28 to 96.3% (by 1.0%); wear resistance – from 0.71 to 0.67% (by 5.6%), calorific value – from 19.04 to 18.75% MJ/kg (by 1.5%). For the first variable factor (PCW content), the change in moisture content and wear resistance are of positive character, while all the other parameters meet the requirements for fuel pellets for non-industrial use of B-class. The mechanical durability value, though less than 96.5%, can be raised by slightly increasing the dose of additives or by reducing the initial moisture level of the chips.



a



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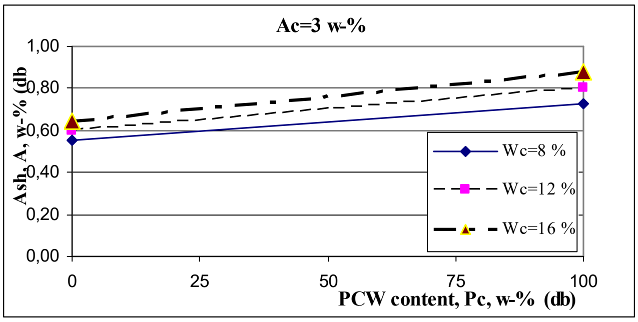
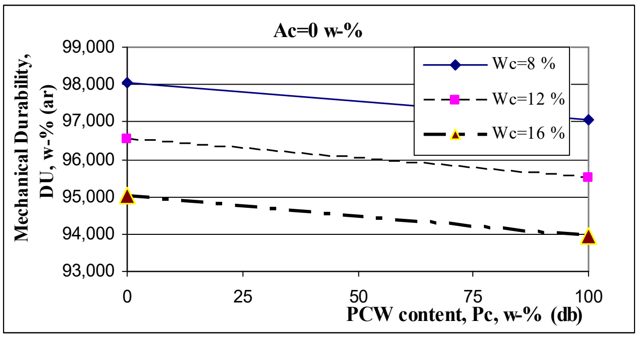


c

Fig. 2. The dependence of the <u>ash content</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %



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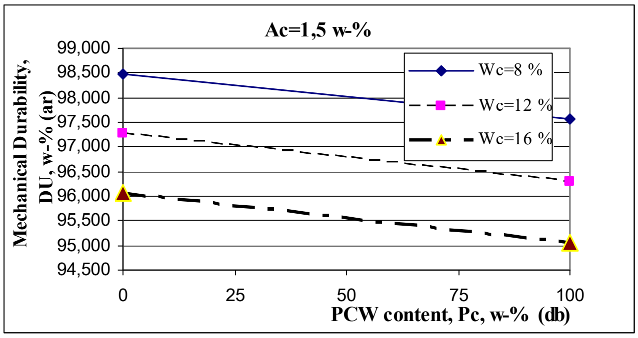

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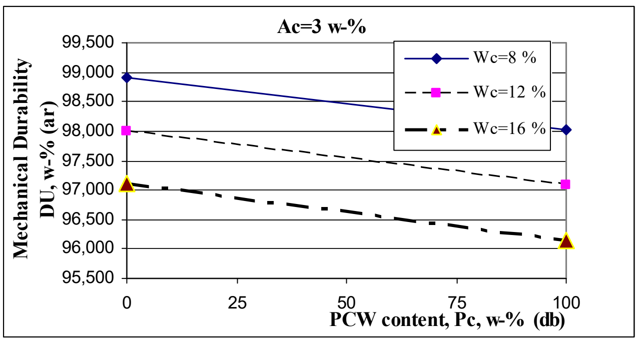


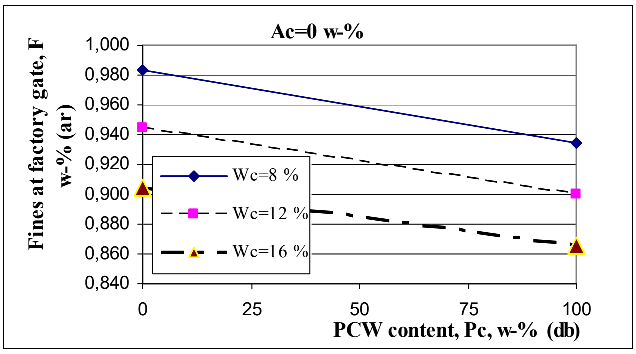
c

Fig. 3. The dependence of the <u>mechanical durability</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

The studies revealed that for pellets with a 100% PCW content with no additives, the chips initial moisture content (8-16%) has varied effects jn their characteristics namely, there is an increase in: ash content – from 0.364 to 0.464% (by 24.7%); moisture content – from 6.32 to 10.9% (by 72.5%); bulk density – from 630.6 to 649.8

kg/m3 (by 3%), while all the other tested pellet parameters decrease: mechanical durability – from 97.06 to 93.98% (by 3.9%); wear resistance – from 0.94 to 0.86% (by 8.5%); calorific value – from 19.05 to 18.89 MJ/kg (by 6.1%).



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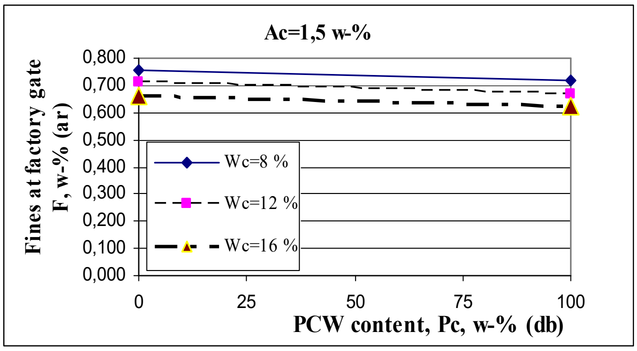

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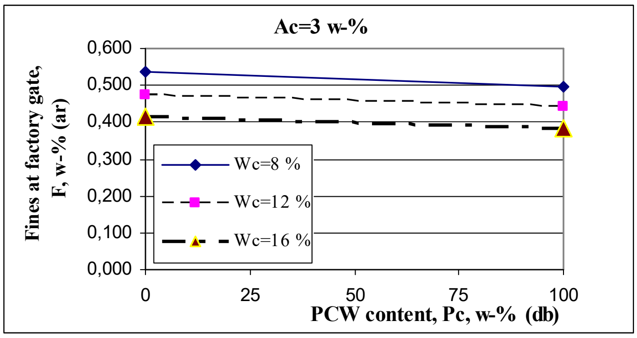
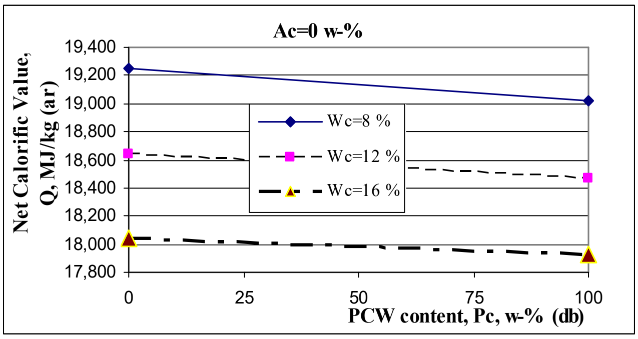


c

Fig. 4. The dependence of the <u>fines at factory gate</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %



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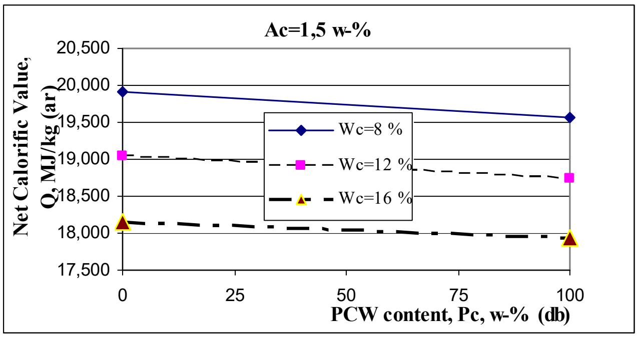

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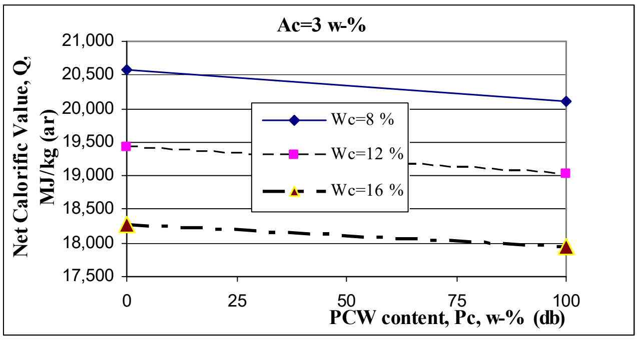


c

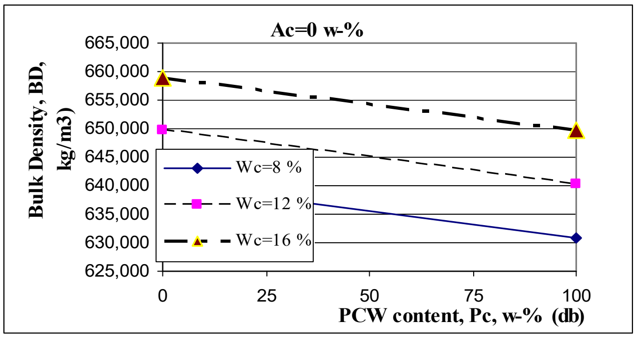
Fig. 5. The dependence of the <u>net calorific value</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

For the second variable factor (chips moisture content), the change in the bulk density is of positive character. All the other parameters need to be corrected by drying wood particles and regulating surface moisture prior to blending in order to ensure the moisture content within a 11-12% range, since smaller moisture level would lead to increased energy consumption during the pellets manufacture.

The results of the experiments also show that the properties of pellets, with a 100% PCW content and chips initial moisture of 12%, are strongly affected by the additive content (0-3%), that is there is an increase in: ash content – from 0.41 to 0.81% (by

97.5%); moisture content – from 8.61 to 9.45% (by 9.8%); mechanical durability – from 95.52 to 97.08% by 1.6%); calorific value – from 18.47 to 19.03 MJ/kg (by 3%); bulk density – from 640.2 to 659.8 kg/m3 (by3.1%), while wear resistance decreases from 0.9 to 0.44% (by 51.2%). For the third variable factor (additive content), the changes in bulk density, mechanical durability, calorific value, and wear resistance are of positive character. The increased ash content is accounted for by using starch as an additive the ash content of which being 4%. Besides starch is able to intensely absorb the initial moister, which results in increased moister content of the fuel pellets. Since the standard EN 1496-2 does not allow the additives to exceed 2%, then it is possible, by meeting the given requirement, to obtain fuel pellets for non-industrial use which would correspond to class B. Moreover, the use of additives allows the pelletizing of chipped material to be made at less energy consumption at an average pressure of 20-100 MPa.



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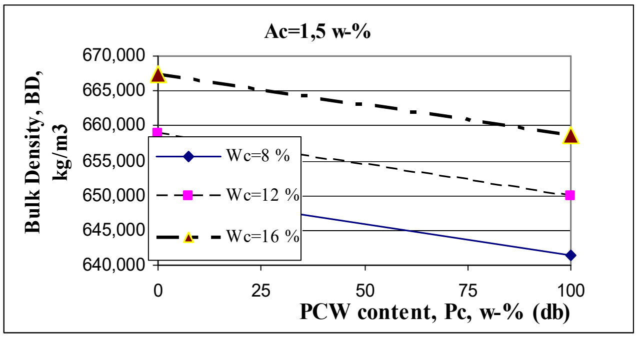

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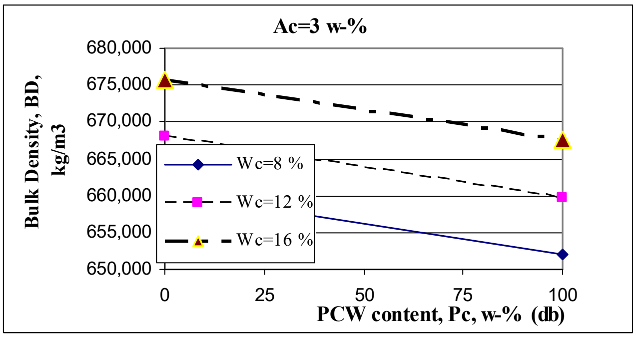

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Fig. 6. The dependence of the bulk densit of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

A change (decrease or increase) in the physical and mechanical properties of wood pellets with increased PCW content is caused by the following reasons:

- age characteristics of PCW – 20-50 years;
- reduction of lignin content in PCW (by 18 to24 % for hardwood and for softwood from 28 to 30 %) as the main component of chips for quality bonding and pressing;
- contamination with soil or sand;
- contamination during use, storage and transport;
- presence or high content of bark;
- presence or high content of inorganic or organic additives;
- initial PCW ash content;
- presence of coatings (paint);
- chemical treatment;
- the use of wood preservatives;
- the presence of flammable substances (glue, tar, oil, plastics, laminates);
- higher initial moisture of wood particles – 16%;
- fractional composition of chips;
- temperature of the chips.

The large number of factors effecting the properties and quality parameters of fuel pellets has motivated extension of the studies on fuel pellets production from PCW of various origin and sources. In this connection, a classification of PCW, as raw material for fuel pellets production, has been developed (Table 21) based on Table 3 and the developed PCW classifier [20]

Table 21. Classification of woody biomass for experimental studies of test pellets

Code	Sub-group source	Kind	Varieties
By-products and residues from wood processing industry			
1.2.1.1	Without bark, Broadleaf	Wood waste from woodworking and machining	Waste, cuttings, shavings from solid wood in its natural state
			Waste, cuttings, shavings from derived timber products and other treated wood (with no harmful contaminants)
1.2.1.2	Without bark, Coniferous	Wood waste from woodworking and machining	Waste, cuttings, shavings from solid wood in its natural state
			Waste, cuttings, shavings from derived timber products and other treated wood (with no harmful contaminants)
Used wood (recovered wood, post-consumer wood)			
1.3.1.1	Without bark, Broadleaf	Blends	Oak, beech, birch, ash, hornbeam, maple and other
1.3.2.1	Without bark, Coniferous	Blends	Pine, spruce, fir, larch, cedar and other
1.3.3.1	Wood-based panel	Composite materials	Particleboards (PB), MDF, OSB, plywood and other composite materials
1.3.3.2	Packaging	Palettes	Palettes made from solid wood such as: Europalettes, industrial palettes made from solid wood
			Palettes made from derived timber products
			Other palettes with composite materials
		Boxes	Transport cases, crates made from solid wood
			Transport cases made from derived timber products
			Boxes for fruit, vegetables and ornamental plants as well as similar boxes made from solid wood
			Ammunition boxes
		Cable reels	Made from solid wood (made before 1989)
			Made from solid wood (made after 1989)
1.3.3.3	Waste wood from the construction industry	Waste wood from buil-ding sites	Solid wood in its natural state
			Derived timber products, barked wood, treated solid wood (with no harmful contaminants)
		Waste wood from tearing down and sorting out	Boards, false ceilings, planks from interior works (with no harmful contaminants)
			Door leaves and frames (with no harmful contaminants)
			Profile boards for the fitting out of rooms, ceiling panels, ornamental beams etc. (with no harmful contaminants)
		Waste wood from demolition and restoration work	Chipboard used in construction
			Wood used in construction for load-bearing elements
			Timber framework and rafters
1.3.3.4	Furniture	Different setting	Furniture, solid wood in its natural state
			Furniture, with no halogenated organic compounds in the coating
1.3.3.5	Municipal waste wood	Blends and mixtures	Various wood used in horticulture and landscaping, impregnated garden furniture
			Various wood used in agriculture
			Other blends and mixtures
1.3.3.6	Solid domestic waste wood	Blends and mixtures	Blends and mixtures of woody biomass

Re-use/recycling. The waste wood Sub-group source may be used for the manufacture of fuel pellets, active carbon/industrial charcoal and the production of synthetic gas as well as in incineration and gasification plants that are licensed pursuant to the Fourth Ordinance on the Imple-mentation of the Federal Emission Control Act and with regard to emissions are subject to the Seventeenth Ordinance on the Implementation of the Federal Emission Control Act. During these procedures, the organic pollutants contained in the waste wood are completely destroyed due to the high temperatures. Heavy metals are bound as solid in the residues or dispersed during waste gas purification. Only certain pollution-free or low-pollution waste woods can be considered for use in manufacturing derived timber products. Compliance with this requirement is guaranteed by binding pollutant limit values, including relevant sampling and analysis provisions, for the wood chips produced for use as raw materials for the manufacture of derived timber products. Waste wood processed in this manner for the derived timber products industry ceases to be waste and can be processed there as a primary raw material.

Comparative studies of fuel pellets with different PCW. The raw material for the experiments on manufacturing fuel pellets was woody biomass, according to the classification of PCW (Table 3, Sub-code). To compare the properties of pellets from PCW, waste from virgin wood was taken. According to the developed technology for producing fuel pellets from PCW with different woody biomass the following operating parameters for pelletizing process were proposed:

- wood particles selected sample – 100%;
- particles moisture prior to pressing – 12%;
- fractional composition: less than 3.15 mm – > 97%; less than 2.0 mm – > 90%; less than 1.0 mm – > 50%; less than 0.1 mm – < 5%;
- chips bulk density – 200-250 kg/m^3;
- additives – 0%;
- hole diameter – 6 mm;
- temperature range for compression – 90-100 °C;
- compacting pressure – 20-150 MPa;
- distance between the die and rollers – 0.3 mm;
- the ratio of the length of the die channel to its diameter – 3.5;

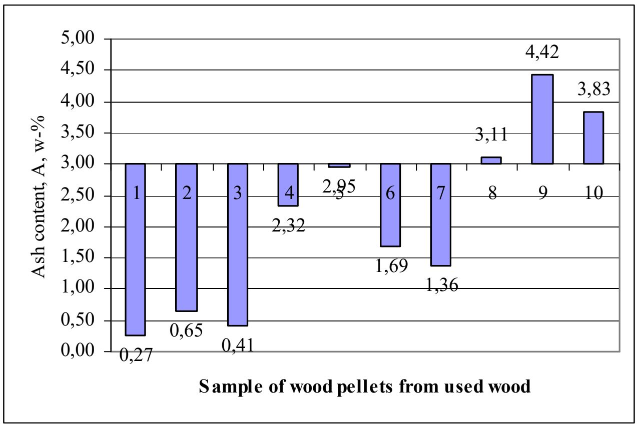
Fuel pellets test was performed according to the standards EN methodology.

Results of comparative experimental study. Data obtained from the physical and mechanical testing of experimental fuel pellets from different PCW (ten samples) for moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density, diameter and length are given in Table 22.

Table 22. Comparative analysis of the properties of wood pellets from the virgin wood and used wood, the results of the research

Parameter	Unit	Method EN	Limit EN B	The results of testing wood pellets from different origins and sources of biomass (Table 3)									
				virgin wood		**used wood – recovered wood, post-consumer wood**							
Origin and source		14961-1		1.2.1.1 Broadleaf	1.2.1.2 Coniferous	1.3.1.1 Broadleaf	1.3.2.1 Coniferous	1.3.3.1 WBP	1.3.3.2 Coniferous	1.3.3.3 Coniferous	1.3.3.4 Furniture	1.3.3.5 Blends	1.3.3.6 Blends
Diameter, D	mm	16127	6±1	6.2	6.1	6.2	6.1	6.3	6.2	6.2	6.4	6.4	6.3
Length, L	mm	16127	≤40	≤3.15 mm length ≤40 mm, maximum ≤45 mm (1 %)									
Moisture, M	w-%	14774-2	≤10	9.5	8.2	8.6	7.9	7.6	8.0	7.7	8.6	8.9	9.6
Ash content, A	w-%	14775	≤3.0	0.27	0.652	0.41	2.322	2.952	1.685	1.363	3.111	4.424	3.825
Mechanical Durability, DU	w-%	15210-1	≤96.5	96.55	99.2	95.52	98.31	95.64	96.65	97.25	93.44	92.63	92.81
Fines at factory gate, F	w-%	15149-1	≤1.0	0.94	0.452	0.9	0.651	1.112	0.78	0.886	1.2	0.954	1.545
Net Calorific Value, Q	MJ/kg	14918	≤16.0	18.64	19.28	18.47	17.62	15.8	18.22	16.9	16.8	18.6	15.36
Bulk Density, BD	kg/m^3	15103	≥600	649.6	660.7	640.2	652.3	610.5	654.6	632.8	612.2	611.9	605.8
Additives	w-%		≤2	0	0	0	0	0	0	0	0	0	0
Sample of wood pallets				1	2	3	4	5	6	7	8	9	10

For the sake of convenience of analysing test parameters of all 10 samples, nomograms for each fuel pellet characteristics have been constructed (Fig. 7-8).



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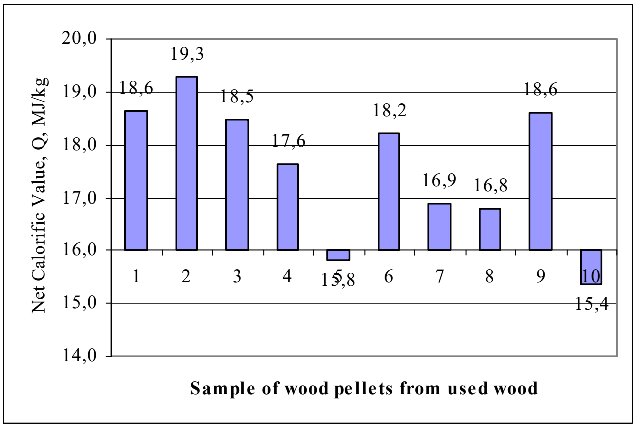

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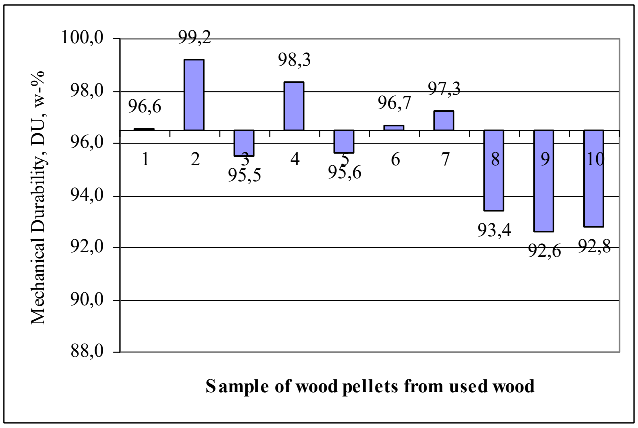

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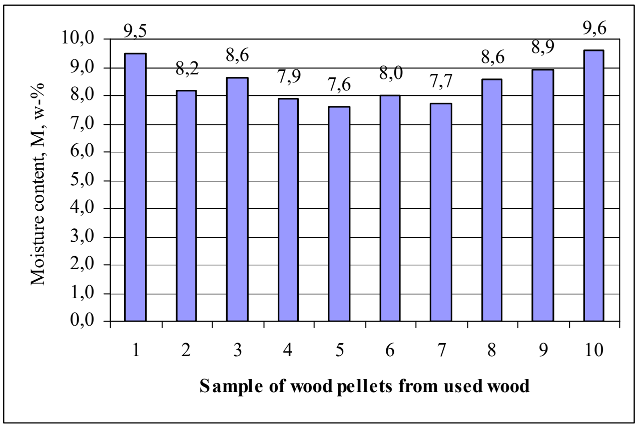
***Fig. 7. Nomograms for ten samples of fuel pellets from different used wood for:** a) Ash content; b) Net Calorific Value; c) Mechanical Durability*



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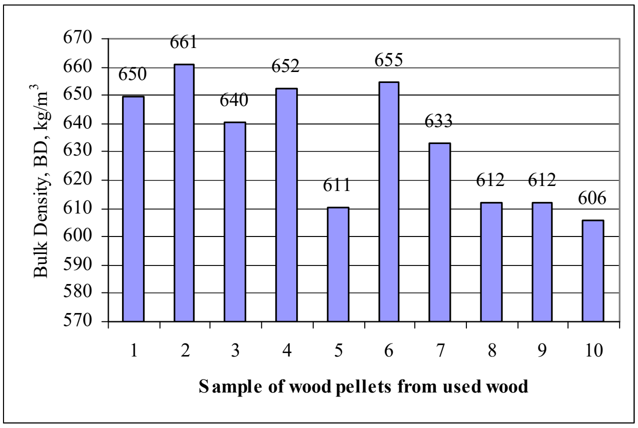

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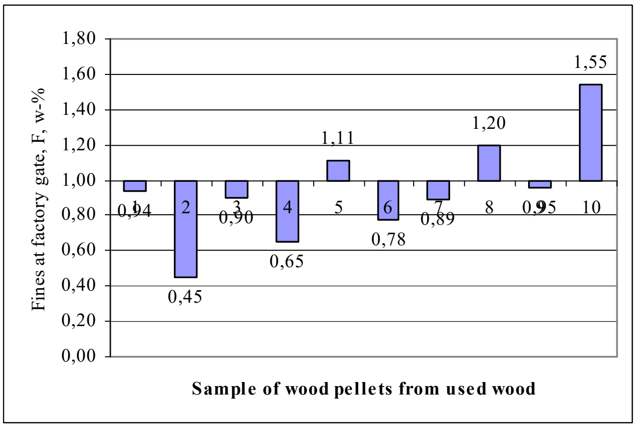

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***Fig. 8. Nomograms for ten samples of fuel pellets from different used wood for:** a) Moisture content; b) Bulk Density; c) Fines at factory gate*

The nomograms, constructed according to the results of comparison studies, gave an insight into the nature of the used biomass: two samples from virgin wool and eight samples of PCW of various origin. The values for the controlled parameters of the samples were compared to normative values for fuel pellets of class B.

The value for ash content in samples 8, 9, and 10 exceeded the normative value of 3% and, respectively amounted to 3.11%, 4.42%, and 3.83%, which might have been caused by PCW contamination introduced during the process of usage, storage, transportation; the presence of increased content of bark; the presence of increased content of either organic or inorganic foreign material; chemical treatment (wood preservation, impregnation, modification); the presence of surface coating (varnish, paint, enamel, etc.).

The calorific value for eight samples were lower than the normative value of 16 MJ/Kg for fuel pellets of class B, which was due to the presence of flammable material in some samples (resin, oils, plastic, laminate) that have high combustion heat level. Samples 5 and 10 showed reduced calorific value, which stems from natural ash content in PCW and the presence of flammable material such as glues that have low combustion heat value.

The mechanical durability for five samples was lower than the normative value of 96.5%, which is explained by: age characteristics of the PCW; species composition; reduced lignin content in some PCW; presence of increased content of bark; particles initial moisture content; fractional composition of the chips; the temperature of the chips. In the other five samples, the mechanical durability value was in compliance with EN14961-2:2011 for pellets of class B. The parameter such as wear resistance had a deviation (1%) from the normative value, which was possibly due to contamination with soil or sand; contamination introduced during utilization, storage, transportation; increased particles initial moister content. The other controlled parameters such as bulk density, moister content, diameter and length of the fuel pellets in all of the samples were in compliance with EN 14961-2:2011 for pellets of class B.

The production process for commercial manufacturing fuel pellets from PCW should include the following stages: segregation of the wood and foreign material (contaminants), crushing the wood to a particle size of no more than 25×25×2 mm; drying; rechipping the particles to a size of more than 4mm; mixing of the chipped material with water and vapor; pelletizing on the pellets making mill; the pellets screening to separate the fines; packing the end-product. The production line and the auxiliary premises should be located over an area of about 600-700 m^2. The approximate consumption of material resources will amount to: electric power – estimated 120 kW per tonne of finished product; water vapor – 70 kg/tonne; water – 10 kg/tonne; heat consumption for wood drying – about 1 MWh/tonne for dried wood with the initial moister content of 35-40%. A team of 8 to 9 men will suffice to serve the line in operation. The recoupment the enterprise will depend on the line production capacity, the type of equipment installed, raw material cost, market price for the end-product, the level of manufacturing expenses. The maximum economic gain is likely to be found at those enterprises which will make a maximum use of PCW since the raw material cost will be minimal there. An estimated bound box of the line with a capacity of 2 tonnes per hour, on condition of exporting the product at a price of 70-90 euro/tonne , will make up 15 to 20 working months. The analysis of the existing pelletizing lines shows the need for upgrading individual units and installation of devices, which would jointly provide for manufacturing quality fuel pellets from PCW.

In this connection, the following measures have been taken:

- The improvement of the equipment of the fuel pellets production line.
- The improvement of the equipment of the drum chippers, in particular they need to be fitted with a net-like insert for chip sizing. This will eliminate the need for further sizing and, consequently, further chipping of PCW. In order to enhance the chippers cutting performance and improve the quality of the produced chips, the cutting part of the machine needs to be made in the form of several sections where the cutters in the adjacent section should be installed at the right angle relative to each other.
- The development of the temperature control system for the pelletizing die.
- Upgrading the system of control over the pelletizing process with the aid of microprocessor-based autoproportioner.
- The improvement of the chips moisture content controller at the point of entry, and the digital stabilizer of moisture at the point of exit.
- Upgrading the blender for dry and wet chips with partial control of feed speed depending on the loading of engine drive.
- Upgrading the gravity segregator for the chipped material and impurities.
- Installation of metal detector on the line at the point of entry, a suspended magnetic strip and magnetic vibrating screen – the moving floor.

Conclusions and recommendations

Conclusion with respect to the work as a whole:

- The topicality of PCW usage for fuel pellets manufacture has been substantiated.
- On the basis of ideas, hypotheses, approaches and means, there have been formulated the aim, object, subject, and tasks of the studies.
- Carried out here was a detailed analysis of the European standards EN which set requirements for solid biofuel (fuel pellets) depending on the biomass used, its origin; also these standards define the main technical specifications, fuel quality and standardized methods for its determination.
- A thorough study has been conducted on the biomass raw material base including PCW for manufacturing fuel pellets.
- A multifactorial experiment has been performed according to the procedure of the study.
- Investigated was the influence of the PCW content within a 0 - 100% range of chip moisture content, and additive content upon the physical-and-mechanical properties of the fuel pellets: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.
- A comparative analysis of physical-and-mechanical properties of fuel pellets for their compliance with the standards has been made for 10 biomass samples: two samples included pure waste form broadleaved and coniferous species, and eight samples – PCW of various sources and origin: in blended – and pure forms.
- The equipment for manufacturing fuel pellets form PCW has been developed for PCW preparation and pelletizing.
- An estimation has been made for socio-economic efficiency resulting from the implementation of the practical recommendations for manufacturing fuel pellets from PCW.

Conclusions with respect to the studies:

- Blending waste (used wood) materials with wood sawdust to make pellets from such blends can result in an acceptable pellet ash content, i.e., 3%.
- Blending waste (used wood) materials with wood sawdust to make pellets from such blends produces pellets of acceptable mechanical strength.
- Blending waste (used wood) materials with wood sawdust exspands the raw material base needed to make fuel pellets.
- Waste (used wood) biomass substances that are presently being landfilled can be used in pellet manufacturing. This will reduce the pressure on landfills.
- Such waste biomass substances are available at a negative cost, unlike wood sawdust, so pellet production costs will be lower.

Conclusion with respect to the PCW issue:

- Monitoring of PCW in Ukraine has been fulfilled

- The sources and PCW origin have been examined: solid domestic waste, municipal waste, commerce (package, pallets), construction waste, wood-processing industry by-products and residue, and others.
- The amount of PCW produced in Ukraine has been estimated, which made up 2.0 million tonnes in 2012.
- Classification has been developed with reference to the degree of PCW contamination, PCW source and origin as well as corresponding categories and codes are provided.
- It has been found that the proposed classification, on the basis of the most important characteristics, represents adequately the source and origin for production of solid biofuel – fuel pellets form PCW.
- It has been shown that there is an obvious need for PCW identification in order to obtain information on physical-and-mechanical properties considering that PCW is realizable additional biomass for obtaining a quality product.
- It has been proved that 50% of PCW (1.0 million tonnes) is suitable for energy use in particular for producing fuel pellets.

Conclusions with respect to the analysis fo PCW-containing fuel pellets:

- For the purpose of the end – product identification, it has been proposed, by applying the above mentioned classification, to perform differentiation of the biofuel, and PCW – made fuel pellets in particular, based on the raw material (here: PCW) origin.
- The determination of the particle-size distribution was done by using vibrating screen with mesh size of 3.51mm and under. The fraction composition of chip for various PCW samples, according to the experimental results, made up: < 3.15mm – 97.2 – 98.1%; < 2.0mm – 90.3 – 91.4%; < 1.0mm – > 54.7 – 62.2%; < 0.1mm – < 2.8 – 4.3%, which is in compliance with the requirements of EN 15149-2:2010 (DSTU-P CEN/TS 15149-2:2009).
- Investigated was the influence of PCW content, chips moisture content and additive content on the physical-and-mechanical properties of PCW-containing fuel pellets: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density, – these having been determined by standard methods.
- It has been found that the PCW content within the range of 0-100% has a linear dependence on various additive contents. In particular, at a 1.5% additive content and the chips moisture content of 12% prior to pressing, the ash the increases from 0.43 to 0.61% (by 41.8%), while all the other tested parameters of the fuel pellets are reduced: moisture content – from 9.90 to 9.03% (by 9.8%), mechanical strength – from 97.28 to 93.3% (by 1.0%), wear resistance – from 0.71 to 0.67% (by5.6%), calorific value – from 19.04 to 18.75 MJ/kg (by 1.5%), bulk density – from 658.8 to 650 kg/m^3 (by 1.3%). For the first variable factor (PCW content), the change in moisture content and wear resistance is of positive character, all the other parameters, are in compliance with the requirements for fuel pellets of non-industrial use, class B. The mechanical property, though less than 96.5%, is possible to raise in this case, by a slight increase in the additive content or by reducing the initial moisture content of the particles.
- It has been established that for the fuel pellets with a 100% PCW content and without additives, the chips moisture content (ranging from 8 to 16%) has different effects on the change of fuel pellets characteristics, namely, there is an increase in: ash content – from 0.364 to 0.464% (by 24.7%), moisture content – form 6.32 to 10.9% (by 72,5%), bulk density – from 630.6 to 649.8 kg/m^3 (by 3%), while all the other tested parameters of the pellets decrease: mechanical strength – from 97.06 to 93.98% (by 3.9%), wear resistance – from 0.94 to 0.86 (by 8.5%), calorific value – from 19.05 to 17.89 MJ/kg (by 6.1%). For the second variable factor (chips moisture content), the change in the bulk density is of positive character. All the other parameters need to be improved by way of drying the wood particles and dosing the surface moisture content prior to blending in order to ensure the moisture content prior to pressing to be within the range of 11-13% since lower moisture content leads to increased energy consumption during the pelletizing process.
- It has been revealed that the properties of pellets with a 100% PCW content and the chips initial moisture content of 12%, are essentially influenced by the additive content (0-13%), namely, there is an increase in: ash content – from 0.41 to 0.81% (by 97.5%), moisture content – from 8.61 to 9.45%

(by 9.8%), mechanical strength – from 95.52 to 97.08% (by 1.6%), calorific value – from 18.47% to 19.03 MJ/kg (by 31%), bulk density – from 640.2 to 659.8 kg/m^3 (by 3.1%), while the wear resistance decreases from 0.9 to 0.44% (by 51.2%). For the third variable factor (additive content), the change in bulk density, mechanical strength, calorific value, and wear resistance are of positive character. The increased ash content is 4%, was used as an additive. Besides, starch as able to intensely absorb initial moisture, which resulted in increased moisture content of the fuel pellets. Since the standard EN 14961-2 does not permit the additive content to exceed 2%, then, on satisfying this requirements, it is possible to obtain fuel pellets for non-industrial use in accordance with class B. Besides, the use of additives allows pelletizing of chipped material to be performed with lower energy consumption – at average pressure values of 20-50 MPa.

- Obtained are adequate mathematical models of the fuel pellets parameters depending on the three variable factors: PCW content, chips moisture content, and additive content.
- A comparative analysis was made concerning the properties of fuel pellets made from PCW of various origin for the following parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.
- It has been found that the ash content exceeded the normative value (3%) in 3 of 10 samples, which is possibly due to PCW contamination with dirt or sand; contamination in the process of usage, storage, transportation; availability or high content of bark; availability or due to increased content of either organic or inorganic matter; chemical treatment (preservation, impregnation, modification); the presence of surface coating (varnish, paint, enamel) and others.
- It has been found: the lower ash content in fuel pellets, the higher their calorific value.
- It has been revealed that mechanical strength (durability) for five samples was lower than the normative value (96.5%), which is attributable to age characteristic of the PCW; the species composition, reduced content of lignin in some kinds of PCW, the presence of increased content of bark, higher initial moisture content of the particles, fraction composition of the chips, the temperature of the chips.
- It has been found that mechanical strength of fuel pellets made from PCW, as the main limiting factor, can be increased by reducing the initial moisture content of the particles (energy consumption increases in this case) and introducing additives to 2% (by the user's agreement).
- It has been established that PCW (in its characteristics) is not inferior to other kinds of biomass, and can be used for manufacturing solid biofuel – fuel pellets.
- It has been proved that fuel pellets made from PCW meet the requirements of the EN 14961-2:2011 standard for pellets of class B.

Conclusions with respect to solving socio-economic problems:

- It has been shown that the implementation of the developed technological techniques concerning the use of PCW for fuel pellet production will make it possible to enhance the economic efficiency of their manufacturing as well as to achieve significant economy of primary wood raw material.
- It has been found that PCW-containing fuel pellets are particularly advantageous for premises heating due to their high calorific value, they are convenient in storage and handling in automatic combustion units, they are not flammable due to lack of dust in them, also they do not contain any allergenic substances that could cause allergy in people.
- The use of PCW for fuel pellets production results in enormous saving on costs. The fabrication of such pellets does not involve any chemical additives under high pressure. The environmental impact from burning PCW-containing pellets in minimal since the amount of the resulting ash in the combustion units is insignificant, There exist many other advantages, For example, energy-intensity of one kilogram of woody pellets and 0.5 liter of diesel fuel is the same.
- It has been estimated that about 2 million tonnes of PCW was produced in 2012 in Ukraine, the energy potential being 0.936 million tonnes of equivalent fuel (27.442 PJ or 7.623 billion kWh). Converting the amount of PCW produced in 2012 into fuel (by distribution: 50% – chips, 25% fuel pellets, 25% fuel briquettes), would make it possible to increase the energy potential to 1.024 million tonnes of equivalent fuel, that is by 9%.
- The calculations show that with this sizable energy potential (excluding firewood) consisting of wood waste and PCW produced in 2012 and estimating at 6.438 million tonnes (2.703 million tonnes of equivalent fuel or 79.4 PJ or 22.056 billion kWh), it is possible to increase it by converting the giv-

en resources into energy fuel. The resulting calculations indicate that the increase could make up to 24% that is the energy indexes will amount to: 3.548 million tonnes of equivalent fuel or 104.00 PJ or 28.889 billion kWh. With annual electricity production in Ukraine in 2012 being 198 billion kWh, this would amount to 14.6% or 19.2% of the annual energy consumption.

Recommendations concerning raw material:

- PCW sorting is to be performed according to the established categories (degree of contamination): PCW-1 – virgin and mechanically processed wood with insignificant contamination by natural compounds (paraffin, ceresine, petrolatum, wax, oil and others) as well as the wood coming from natural disasters; PCW-2 – wood and wooden items treated without wood preservatives and without halogenated organic compounds in surface coating; PCW-3 – wood and wooden items treated without wood preservative and with halogenated organic compounds in surface coating; PCW-4 – wood and wooden items treated with wood preservatives,
- For categories PCW-3 and PCW-4, thorough examination shall be done concerning the PCW impurities composition, in particular for presence of wood preservatives: antipyren, antiseptic material, insecticides, fungicides, biocides, complex compounds and others.
- PCW biofuel mixtures shall be excluded from manufacturing fuel pellets for household heating as long as these contain halogenated organic compounds that had been used for preservation of virgin wood.
- A PCW biofuel mixture containing both chemically treated and chemically untreated wood shall be classified as that which is chemically treated.
- Rot PCW shall be excluded from manufacturing fuel pellets.
- PCW biofuel mixtures containing chemically treated material shall be checked for presence of polychlorinated terphenyls (PCT), polybrominated biphenyls (PBB) with concentration of 50 mg/kg and over, as well as fraction of coal tar, which contains benzapyren and its components exceeding the normative values.
- An analysis of chemically treated wood shall be made concerning the presence of chemical elements such as arsenic, cadmium, cooper, mercury, plumbum, sulphur, nitrogen, chlorine, zinc and others as well as their compounds, in accordance with the standards EN 15289:2011 and EN 15297:2011.

Recommendation on the raw material preparation (treatment):

- If the PCW contains some harmful elements or their compounds exceeding the normative value, it is necessary that a thermo-chemical treatment should be provided at a temperature of 100-130°C or else burn the fuel in combustion units of capacity over 100 kW.
- Relevant methods and ways have been developed to remove various impurities from the PCW.
- The PCW suitable for fuel pellets manufacturing should be cleaned by one of the following ways: surface cleaning (for solid PCW) on machine tools such as brushing machine, milling machine, grinding machine, sandblast machine and other; internal cleaning (for chipped PCW) by equipment such as air separator, vibratory feeder, air cleaner, magnetic strip, metal detector, swinging sieve.
- In order to reduce ash content in PCW-containing fuel pellets, it is necessary that the PCW should be cleaned form dirt or sand; it is necessary to avoid contamination introduced during handling, storage, transport; it is necessary that bark content should be reduced; the production process should be kept free from PCW containing inorganic or organic impurities, chemically treated wood including finishing (varnish, paint, enamel and others).
- The used composite material, as a raw material of high calorific value, (WPB, OSB, MDF and others) can be utilized for manufacturing fuel pellets only after they have been cleaned from polyvinylchloride films (PVC), plastics, laminate.

Recommendations concerning the production process:

- With respect to the fuel pellets production process, the following measures have been realized:
- The improvement of the existing fuel pellets production techniques, which make use of traditional primary raw material, has been carried out.
- The development of the technological process for converting PCW into solid fuel: fuel pellets. Accordingly, it was proposed to establish an area for PCW preparation which will involve: PCW sort-

ing for contamination, wood species, the type of the used construction material, etc.; removal of impurities and various foreign material; removal of plastics, non-ferrous and ferrous metals from both solid (unchipped) and chipped PCW.

- The following measures should be effectuated: to install a metal detector at the point of entry – before loading of the chipped material; to fix a suspended magnetic strip over the moving belt conveyor and mount a magnetic vibrating screen called "moving floor" in the mechanized storehouse.
- To install a scraper conveyor for the purpose of providing a controlled speed of the raw material feed to the disk separator (gravity segregator) to remove stones, sand and other impurities.
- To install a dynamic segregator which, during the drying process, will separate the dry and fine fraction form the wet and coarse particles returning the latter to the rotary chipper.
- The chipped and dried PCW chips are to be fed to the cyclone where they settle down due to the centrifugal force and then are fed via the upgraded screw conveyor to the pellet mill bunker.
- To install inside the bunker a device which will prevent the chips form becoming caked (bridging).
- To upgrade the system of automatic control over the pelletization process by means of microprocessor-based autoproportioner.
- To upgrade the blender for dry and wet chip with partial control of feed speed depending on the loading of the engine drive.
- To equip the wood pellets line with control system of temperature conditions for the pelletization process as well as with system of the chip moisture control at the point of entry together with a device for water supply directly into the pellet mill.
- To equip the wood pellet line with a digital moisture content stabilizer at the point of exit since the pellets after pelletizing have rather a high temperature and low mechanical strength.
- To provide transport of the hot pellets by an elevator (noria) to the cooler ensuring sucktion of the non-pelletized PCW chip into the cyclone.
- To provide packing of the PCW-containing fuel pellets into bags weighing as much as 15 kg.

Recommendations for fuel pellet production:

1. Developed are operating conditions parameters for fuel pellet production process.
2. Determined is the rational composition of fuel pellets with various PCW contents for broadleaved – and coniferous species (1:1), as well as composite material (not more than 50%) with consideration of pressability.
3. According to the developed technology for producing fuel pellets from PCW with different type ofwood biomass, the following operating conditions parameters for pelletizing process have been proposed:

- wood particles selected sample – 100%;
- particle moisture before pressing – 12%;
- fractional composition: less than 3.15 mm – > 97%; less than 2.0 mm – > 90%; less than 1.0 mm – > 50%; less than 0.1 mm – < 5%;
- chips bulk density – 200-250 kg/m^3;
- additives – 0%;
- hole diameter – 6-8 mm;
- temperature range at pressing – 90-100 °C;
- compacting pressure – 50-150 MPa;
- distance between the die and rollers – 0.3-0.6 mm;
- the ratio of the length of the die channel to its diameter – 3.5.

4 Additives might be binding agent or extraneous material: wet mass basis quantity and type (e.g. starch, corn flour, vegetable oil) to be declared.

5 Bulk maximal temperature shall be checked when the pellets leave the final point of loading for delivery to the end-user. i.e leaving the final storage point or the factory: exact value must be declared and compared to ambiant temperature of delivery + 5°C

6 EN 14961-2 has ash melting informative (voluntary) and ENPlus DT temperature is requested and ashing temperature 815 ºC. Ash content is determinated at a temperature 550 ºC.

7 Fines for domestic pellets "The amount of fines shall be checked when the pellets leave the final point of loading for delivery to the end-user. i.e leaving the final storage point or the factory if delivering directly to the end-user". The amount of fines leaving the factory gate shall also be ≤ 1% (unless there is a different agreement between the producer and their customer).

8 Raw material origin and source of PCW has to be stated according to table 1 in EN 14961-1 and Table 3 of this article (1.3 used wood). Chemically treated wood residues from wood, processing and the production of panels and furniture (glued, painted, coated, lacquered or otherwise treated wood, 1.2.1) or used wood (1.3.2, 1.3.3) is included in EN 14961-2, as long as they do not contain heavy metals or halogenated organic compounds as a result of treatment with wood preservatives or coating. Chemically treated wood must meet same threshold values as virgin wood.

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УДК 674.81:662.638 *Докторант С.В. Гайда, канд. техн. наук – НЛТУ України*

Технології виробництва та властивості паливних гранул із вживаної деревини

Розраховано енергетичний потенціал деревної біомаси – відходів деревини та вживаної деревини (ВЖД), який склав у 2012 р. 6,438 млн. т, зокрема, ВЖД – 2,0 млн. т. Обґрунтовано, що, перетворивши дані ресурси у тверді види палива, енергетичний потенціал зросте з 2,703 до 3,548 млн. т у.п., тобто на 24%. Розроблено технологію та удосконалено обладнання виготовлення паливних гранул із ВЖД, як енергоємної сировини. Запропоновано режимні параметри виготовлення паливних гранул, визначено раціональний склад гранул з різним вмістом твердих та м'яких частинок ВЖД листяних та хвойних порід, композитних матеріалів і ін., виходячи із здатності до пресування. Проведено порівняльний аналіз властивостей паливних гранул із різним вмістом ВЖД за такими показниками як вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.

Висновки та рекомендації

Висновки до роботи в цілому:

- Обґрунтовано актуальність та проблемність використання ВЖД для виробництва паливних гранул.
- Сформовано, на підставі ідей, гіпотез, підходів та засобів, мету, об'єкт, предмет та завдання досліджень;
- Проведено детальний аналіз Європейських стандартів EN, що забезпечують вимоги до твердого біопалива (паливних гранул) в залежності від біомаси, її походження, а також визначають основні технічні характеристики, якість палива та стандартні методи його визначення;
- Проаналізовано сировинну базу біомаси, в тому числі ВЖД для виготовлення паливних гранул;
- Проведено багатофакторний експеримент за використання ПФП-2^3 та реалізовано матрицю планувань згідно методики досліджень;
- Досліджено вплив вмісту ВЖД в діапазоні 0-100 %, вологості стружок та вмісту добавок на фізико-механічні властивості паливних гранул – вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.
- Здійснено порівняльний аналіз фізико-механічних властивостей паливних гранул за вимогами стандартів для десяти проб біомаси: двох – з чистих відходів листяних та хвойних порід; восьми – ВЖД різного походження та джерел одержання в чистому та змішаному вигляді;
- Удосконалено обладнання для виготовлення паливних гранул із ВЖД;
- Розроблено технологічний процес з підготовки ВЖД та її гранулювання;
- Розраховано соціально-економічну ефективність від впровадження практичних рекомендацій виготовлення паливних гранул з ВЖД.

Висновки до дослідження:

- Змішування відходів (вживаної деревини) з таким матеріалом як деревна тирса дозволяє одеожани гранули з таких сумішей з прийнятним вмістом золи, тобто 3%.
- Змішування відходів (вживаної деревини) з таким матеріалом як деревна тирса дозволяє одеожани гранули з таких сумішей з прийнятною механічною міцністю.
- Змішування відходів (вживаної деревини) матеріалів з деревною тирсою збільшує поставки сировинної бази, яка необхідна виробництва паливних гранул.
- Відходи (ВЖД) біомаса речовин, які, в даний час, є на звалищах, можуть бути використані у виробництві гранул. Це дозволить знизити навантаження на звалища.
- Такі речовини відходів біомаси, на відміну від тирси, є доступними через низьку собівартість, тому витрати виробництва пелет будуть нижчими.

Висновки до вживаної деревини:

- Проаналізовано джерела походження ВЖД: тверді побутові відходи, муніципальні відходи, торгівля (тара, піддони), будівельні відходи, господарська діяльність, переробна промисловість та інші;

- Здійснено моніторинг ВЖД в Україні;
- Розраховано кількість ВЖД в Україні, яка становила у 2012 році 2,0 млн. т;
- Розроблено класифікацію ВЖД за ступенем забруднення та за джерелами походження з відповідними категоріями та кодами;
- З'ясовано, що запропонована класифікація, на основі найбільш характерних ознак, повноцінно відображає походження та джерела одержання твердого біопалива – паливних гранул з ВЖД;
- Доведено необхідність здійснення ідентифікації ВЖД для отримання інформації про фізичні та хімічні властивості як реальної додаткової біомаси для якісної продукції;
- Обґрунтовано, що 50 % ВЖД (1,0 млн. т) є придатною для енергетичного використання, зокрема, для виготовлення паливних гранул;

Висновки до аналізу властивостей паливних гранул з ВЖД:

- Запропоновано на підставі розробленої класифікації проводити диференціацію біопалива, зокрема паливних гранул з ВЖД, на основі походження ВЖД для можливості проведення ідентифікації даної продукції;
- Визначено гранулометричний склад з використанням вібраційного решета з отворами 3,15 мм і менше. Фракційний склад стружок для різних проб ВЖД за результатами експериментів становив: < 3,15 мм – 97,2- 98,1 %; < 2,0 мм – > 90,3-91,4 %; < 1,0 мм – > 54,7-62,2 %; < 0,1 мм – < 2,8-4,3 %, що відповідає вимогам стандартів EN 15149-2:2010 (ДСТУ-П CEN/TS 15149-2:2009);
- Досліджено вплив вмісту ВЖД, вологості стружок та вмісту добавок на фізико-механічні властивості паливних гранул з ВЖД – вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність, які були визначені стандартними методами;
- Визначено, що вміст ВЖД в діапазоні 0-100 % в паливних гранулах веде себе однаково при різному вмісті добавки (в'яжучого). Зокрема, при витраті добавки 1,5 % та вологості стружок перед пресуванням 12 %, зольність зростає від 0,43 до 0,61 % (41,8 %), а всі інші тестовані параметри гранул спадають: вологість – з 9,90 до 9,03 % (на 9,8 %), механічна міцність – з 97,28 до 96,3 % (на 1,0 %), стиранність – з 0,71 до 0,67 % (на 5,6 %), теплотворна здатність – з 19,04 до 18,75 МДж/кг (на 1,5 %), насипна щільність – з 658,8 до 650 кг/м^3 (на 1,3 %). Для першого змінного фактору (вмісту ВЖД) зміна вологості та стиранності мають позитивний характер, всі інші параметри відповідають вимогам до паливних гранул непромислового використання В класу. Механічна міцність хоч має значення менше, ніж 96,5 %, але підняти її, у даному випадку, можливо – несуттєво збільшивши вміст добавки або зменшивши початкову вологість частинок;
- Встановлено, що для гранул із вмістом ВЖД 100 % та без добавки вологість стружок (при її зміні від 8 до 16 %) по різному впливає на зміну характеристик паливних гранул – зростають: зольність від 0,364 до 0,464 % (на 24,7 %), вологість – з 6,32 до 10,9 % (на 72,5 %); насипна щільність – з 630,6 до 649,8 кг/м^3 (на 3 %), а всі інші тестовані параметри гранул спадають: механічна міцність – з 97,06 до 93,98 % (на 3,9 %), стиранність – з 0,94 до 0,86 % (на 8,5 %), теплотворна здатність – з 19,05 до 17,89 МДж/кг (на 6,1 %). Для другого змінного фактору (вмісту вологи стружок) зміна насипної щільності має позитивний характер. Всі інші параметри необхідно корегувати шляхом висушування деревних частинок та дозуванням поверхневої вологи перед змішуванням для забезпечення вмісту вологи перед пресуванням в межах 11-13 %, оскільки менше значення її приводить до збільшення енергозатрат під час виготовлення гранул;
- Виявлено, що на властивості гранул із вмістом ВЖД 100 % та початковою вологістю стружок 12 % суттєво впливає вміст добавки (0-3 %) – зростають: зольність від 0,41 до 0,81 % (на 97,5 %), вологість – з 8,61 до 9,45 % (на 9,8 %); механічна міцність – з 95,52 до 97,08 % (на 1,6 %), теплотворна здатність – з 18,47 до 19,03 МДж/кг (на 3 %), насипна щільність – з 640,2 до 659,8 кг/м^3 (на 3,1 %), а стиранність спадає з 0,9 до 0,44 % (на 51,2 %). Для третього змінного фактору (вмісту добавки) зміна насипної щільності, механічної міцності, теплотворної здатності та стиранності має позитивний характер. Зростання зольності зумовлене тим, що в якості добавки використовувався крохмаль, який має зольність 4 %. Крім того, крохмаль має здатність інтенсивно поглинати початкову вологу, що призвело до зростання вологості паливних гранул. Оскільки стандарт EN 14961-2 дозволяє здійснювати добавки у кількості не більше 2 %, то, забезпечивши дану вимогу, можливо одержати паливні гранули непромислового використання,

що відповідають В класу. Крім того, використання добавок дозволяє проводити грануляцію подрібненого матеріалу з меншими енергетичними затратами – при середніх тисках 20-50 МПа;

- Одержано адекватні математичні моделі залежності показників паливних гранул від трьох змінних факторів: вмісту ВЖД, вологості стружок та вмісту добавок;
- Проведено порівняльний аналіз властивостей паливних гранул з ВЖД різного походження за такими показниками як вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.
- Встановлено, що зольність перевищувала нормативне значення (3 %) у трьох пробах з десяти, що можливо зумовлено забрудненням ВЖД ґрунтом або піском; забрудненням в процесі використання, зберігання, транспортування; наявністю або підвищеним вмістом кори; наявністю або підвищеним вмістом неорганічних або органічних добавок; хімічним обробленням (консервуванням, просочуванням, модифікуванням); наявністю лакофарбових матеріалів (лак, фарба, емаль) та інше;
- З’ясовано, чим менше золи в паливних гранулах, тим вища їх теплотворна здатність;
- Визначено, що механічна міцність у п’яти пробах була нижчою за нормативне значення 96,5 %, що обґрунтовується віковою характеристикою ВЖД; породним складом; зменшеним вмістом лігніну у деяких ВЖД, наявністю або підвищеним вмістом кори; більшою початковою вологістю частинок; фракційним складом стружок; температурою стружок;
- Встановлено, що збільшувати механічну міцність гранул з ВЖД, як основного обмежуючого фактору, можливо зменшуючи початкову вологість частинок (зростають енергозатрати на пресування), додаючи добавки до 2 % (за згодою споживачів);
- З’ясовано, що ВЖД за своїми характеристиками не поступається іншій деревній біомасі і може бути використання для одержання твердого біопалива – паливних гранул;
- Доведено, що паливні гранули з ВЖД відповідають вимогам стандарту EN14961-2:2011 для гранул В класу.

Висновки для розв’язання соціально-економічних проблем:

- встановлено, що впровадження розробок з використання ВЖД для виробництва паливних гранул дозволить підвищити економічну ефективність їх виготовлення, а також значно заощадити первинні сировинні деревні ресурси;
- досліджено, щопаливні гранули з ВЖД є ефективним паливом для опалення приміщень, оскільки мають більшу теплотворну здатність, під час зберігання вимагають невеликої площі, є зручними для переміщення в автоматичних системах спалювання, та не піддаються самозапалюванню, оскільки не містять пилу, а також речовин, які можуть викликати алергійну реакцію в людей;
- заощадження коштів величезне, адже для виготовлення таких гранул використовують ВЖД. Виробництво таких деревних гранул відбувається без жодних хімічних добавок під високим тиском. А спалювання їх у котельнях не шкодить довкіллю, бо навіть кількість золи в котлах є незначною. Існує й чимало інших переваг. Наприклад, енергоємність кілограму деревних гранул і 0,5 літра дизпалива — однакова;
- розраховано, що в Україні у 2012 р. утворилось 2 млн. т ВЖД, з енергетичним потенціалом 0,936 млн. т у.п. (27,442 ПДж або 7,623 млрд. кВт-год). Перетворивши утворену ВЖД за 2012 р. у паливо за розподілом 50 % тріска, 25 % паливні гранули та 25 % паливні брикети можливо збільшити енергетичний потенціал до 1,024 млн. т у.п. , тобто на 9 %;
- прораховано, що, маючи значний енергетичний потенціал (без врахування дров) з відходів деревини та ВЖД за 2012 р. у кількості 6,438 млн. т (2,703 млн. т у.п. або 79,4 ПДж або 22,056 млрд. кВт-год), можливо його збільшити, перетворивши дані ресурси в енергетичні види палива. Результати розрахунку свідчать, що зростання може становити 24 %, тобто енергетичні показники зростуть і будуть становити: 3,548 млн. т у.п. або 104,00 ПДж або 28,889 млрд. кВт-год. При виробництві річної електроенергії в Україні у 2012 р. у кількості 198 млрд. кВт-год, це склало б 14,6 %, або 19,2 % від річного споживання.

Рекомендації до сировини:

1. Здійснювати сортування ВЖД за розробленими категоріями (ступенями забруднення): ВЖД-I – природна та тільки механічно оброблена деревина з незначними забрудненнями натуральними зв’язками (парафін, церезин, петролатум, віск, мастило та ін.), а також деревина від

стихійних катаклізмів; ВЖД-II – оброблена деревина та деревні матеріали без речовин захисту деревини та без галогеноорганічних зв'язків у покриттях; ВЖД-III – оброблена деревина та деревні матеріали без речовин захисту деревини та з галогеноорганічними зв'язками у покриттях; ВЖД-IV – деревина та деревні матеріали, які оброблені речовинами захисту;

2. Для категорій ВЖД-III та ВЖД-IV детально досліджувати склад та матеріал забруднювачів ВЖД, зокрема, на наявність речовин захисту деревини: антипіренів, антисептиків, інсектицидів, фунгіцидів, біоцидів, комплексних препаратів та ін.

3. Не обліковувати біопаливні суміші з ВЖД різного походження та складу для виробництва паливних гранул для побутових потреб, якщо вони містять галогеноорганічні сполуки та важкі метали, які були задіяні для захисту (консервування) первинної деревини;

4. Класифікувати біопаливну суміш з ВЖД, яка складається одночасно із хімічно обробленої і хімічно необробленої деревини, як хімічно оброблену;

5. Не допускати для виробництва паливних гранул гнилої ВЖД.

6. Перевіряти біопаливну суміш з ВЖД, яка містить хімічно оброблений матеріал, на вміст небезпечних складників, які містять поліхлоровані біфеніли (ПХБ), поліхлоровані терфеніли (ПХТ), полібромовані біфеніли (ПББ) концентрацією 50 мг/кг і більше, а також фракції кам'яновугільної смоли, які містять бенз(а)пірен та його сполуки більше норми та порівнювати з допустимими нормативними значеннями.

7. Проводити аналіз хімічно забрудненої деревини на наявність хімічних елементів (миш'як, кадмій, мідь, ртуть, свинець, сірка, азот, хлор, цинк та ін.) та їх сполук у відповідності до методів зазначених у стандартах EN 15289:2011 та EN 15297:2011;

Рекомендації до підготовки (очищення) сировини

8. За наявності у ВЖД шкідливих елементів та їх сполук більше норми необхідно проводити термо-хімічне очищення при температурі 100-130 °С або спалювати в котельних установках потужністю більше 100 кВт;

9. Обґрунтовано способи та методи очищення ВЖД від різних домішок;

10. Придатну для виготовлення паливних гранул ВЖД необхідно очищати одним із способів: поверхневим (для масивної ВЖД) – модернізованими верстатами (щітковим, фрезерним, голко фрезерним, шліфувальним, піскоструйним, пелюстковим); внутрішнім (для подрібненої ВЖД) – устаткуванням (повітряний сепаратор, вібраційний фідер, повітряний очищувач, магнітна стрічка, металодетектор, динамічне решето);

11. Для зменшення зольності паливних гранул з ВЖД необхідно очищати її від ґрунту або піску; уникати забруднення в процесі використання, зберігання, транспортування; очищати та зменшувати вміст кори; не допускати попадання у технологічний процес ВЖД із вмістом неорганічних або органічних добавок; хімічно забрудненої деревини, у тому числі лакофарбових матеріалів (лак, фарба, емаль) та інше;

12. Вживані композиційні матеріали (ДСП, ОСБ, МДФ та інші) повинні бути очищенні від полівінілхлоридних плівок (ПВХ), пластика, ламінату і, тоді, можуть бути використані у виробництві паливних гранул, як сировина з високою теплотворною здатністю;

Рекомендації до технологічного процесу

13. Удосконалено існуючу технологію виробництва паливних гранул, яка використовує традиційну первинну деревну сировину;

14. Розроблено технологічний процес перетворення ВЖД у тверде паливо – паливні гранули. Запропоновано у новій технології запровадити дільницю з підготовки ВЖД, яка включає сортування за забрудненням, за породою, за конструкційними матеріалами та інше; очищення від домішків та різноманітних включень; вилучення пластмаси, кольорових та чорних металів як з масивної, так і з подрібненої ВЖД;

15. Встановити у технологічному процесі детектор-металошукач на початковому етапі – перед завантаженням подрібненої сировини; закріпити підвісну підмагнічену стрічку над рухомим стрічковим транспортер та вмонтувати магнітний просіювач-вібратор під назвою «рухома підлога» на механізованому складі;

16. Забезпечити скребковим транспортером регульовану швидкість подачі сировини до дискового сепаратора (гравітаційного розділювача) для якісного відділення від каменів, піску та інших домішок;

17. Встановити динамічний розділювач, який в процесі сушіння розділяє суху і дрібну фракцію від вологих та великих частинок, повертаючи їх до ротора-подрібнювача;

18. Подрібнену та висушену стружку ВЖД подавати в осадовий циклон, в якому вона за рахунок відцентрової сили осідає на дно, і, завдяки модернізованому шнековому транспортеру, підвозити до бункера гранулятора;

19. Встановити у середині бункера гранулятора пристрій, який перешкоджає злежуванню стружки;

20. Модернізувати систему автоматичного керування процесом гранулювання за допомогою автоматизованого дозатора із мікропроцесорним керуванням;

21. Модернізувати змішувач сухої та вологої стружки із частковим регулюванням швидкості подачі залежно від завантаженості приводу двигуна;

22. Встановити в обладнання лінії перероблення ВЖД на гранули систему контролю температурного режиму гранулювання та системи регулювання вологості стружки на вході з пристроєм подачі води безпосередньо в гранулятор;

23. Запровадити у виробничий процес цифровий стабілізатор вологи на виході, оскільки гранули, які виходять з матриці, мають високу температуру та неміцні;

24. Забезпечити транспортування гарячих гранул вертикальним транспортером – норією в охолоджуючу колонку, забезпечуючи відсмоктування незранульованої стружки ВЖД в циклон;

25. Здійснювати дозування паливних гранул з ВЖД у мішки вагою 15 кг.

Рекомендації до виготовлення паливних гранул

1. Розроблено режимні параметри виготовлення паливних гранул,
2. Визначено раціональний склад гранул з різним вмістом ВЖД листяних та хвойних порід (1:1), композитних матеріалів (не більше 50 %), виходячи із здатності до пресування.
3. У відповідності до розробленої технології для виготовлення паливних гранул із PCW з різної деревної біомаси запропоновано наступні режимні параметри процесу гранулювання: деревні частинки вибраної проби – 100 %; вологість частинок перед пресуванням – 12 %; фракційний склад: < 3,15 мм – > 97 %; < 2,0 мм – > 90 %; < 1,0 мм – > 50 %; < 0,1 мм – < 5 %; насипна щільність стружок – 200-250 кг/м^3; добавки – 0 %; діаметр отворів – 6 мм; діапазон температури пресування – 90-100 °С; тиск пресування (в регуляторі люзу між матрицею та роликами) –10-150 МПа; віддаль між матрицею та роликами – 0,3 мм; співвідношення довжини каналу матриці до її діаметра – 3,5.
4. Добавки можуть бути у вигляді в'яжучого або наповнювача: тип (наприклад, крохмаль, кукурудзяна мука, олія) та кількість до основної маси гранул повинні бути задекларовані.
5. Загальна максимальна температура гранул повинна бути перевірена, коли вони залишають кінцеву точку відвантаження для доставки кінцевому користувачеві, тобто залишивши кінцевий пункт зберігання чи заводу, має бути зафіксована точна температура у відповідності до умов доставки (+5°С).
6. У відповідності до стандарту EN 14961-2 виробник повинен надавати інформацію щодо температури плавлення золи добровільно, а за стандартом ENplus DT температура має становити 815ºС. Зольність необхідно визначати за температури 550ºС.
7. Стиранність для гранул, які використовуються у домашніх умовах, необхідно перевіряти коли гранули залишають кінцеву точку відвантаження для доставки кінцевому користувачеві, тобто коли вони залишають кінцевий пункт зберігання чи заводу. Загальна стиранність гранул після заводу повинна бути ≤ 1% (якщо немає іншої угоди між виробником і клієнтом).
8. Походження сировини і джерел ВЖД повинно бути вказано у відповідності з табл. 1 (EN 14961-1) і табл. 3 цієї статті (1.3 – ВЖД). Хімічно оброблена деревина, яка утворюється під час оброблення деревини та виробництві плит і меблів (склеєна, пофарбована, покрита плівками, лакована або іншим чином оброблена деревина, 1.2.1) або ВЖД (1.3.2, 1.3.3) у відповідності до EN 14961-2, може використовуватись у виробництві паливних гранул, якщо вона не містять важких металів або галогеноорганічних сполук, утворених в результаті обробки деревини або у покриттях. Обмеження для хімічно обробленої деревини є однаковими, що й для первинної деревини.

Ключові слова: вживана деревина, біомаса, енергетичний потенціал, паливні гранули, технологія, властивості гранул, соціо-економічна ефективність.

UDC 630*848:621.86 *Assoc. prof. B.Ya. Bakay – UNFU*

CONSTRUCTION OF MATHEMATICAL MODEL OF SUSTAINABILITY OF A ROUND TIMBER PACK DURING THE OPERATIONS BY A MOBILE MACHINES

The problem of the interaction of round timber during the process of capturing levers grips mobile timber storage machines has been considered. Powered equation bend "beam system" with inclusions in elastic foundation distributed stiffness and type of loads concentrated forces. A singular functions have been used to focus inclusion in the analytical expressions of distributed parameters

Keywords: round logs, grips, interaction, mobile timber storage machines, singular functions.

Introduction. Designing and creating of a new efficient designs of technological equipment for mobile log storage machines, are the complex engineering problems. Their rational solutions are possible when their interactive efforts with gripping round timber are known (such as levers grapple of a mobile machines) [1-3].

Determining the value of the round timber's interaction effort (in bundles or packages of volume 2-10 m^3 or more) of the grips, should be considered as a homogeneous system of round logs, that interact with each other under the action of it's own and external load (eg, compressed logs levers grips).

Condition of question. In works of a Lazaryan V. A. and Konashenko S. Y. there was proposed following. During the exploration of oscillations dimensional rod systems with a lumped inclusions in a distributed mass, stiffness in the base (intermediate elastic supports), the elastic stiffness of the rod, simulate them with the use of pulse functions 1-4-orders. In this case an arbitrary focused inclusion is seen as inclusion in either distributed parameter: the intensity of the distributed mass $m(x)$, the coefficient of elasticity $K(x)$ elastic foundation stiffness $EI(x)$ during the bending of a rod [4, 5].

The singular functions are used for introduction the concentrated impurities in analytical expressions of distributed parameter. Therefore, the differential equation form fluctuations have singular coefficients [5].

A similar method we are using to determine the critical load gripping during lifting beams of the same size, that are aligned along the length. In a certain intersection point, the system of beams forms a "beam" with some elastic, tied between itch other and loaded from the top and elastic ties from the bottom that are considered as elastic support. Differential equations of a bending "beams" contain impulse functions up to 4-th order. Intermediate parameters, that are included in the solutions of these equations and reflect the presence of impurities, are eliminated using recursive relationships. This solution is the only analytical expression in the whole range of the argument and it's expressed only through the initial settings and some influence functions, which are generalized by functions of Krylov. Concentrated loads on a "beam system" in the projection of x axis along the length of "beam" will represent with loads P_i and moments M_i, that are attached to the central axis. The magnitude of these forces will depend on the number of rows of beams that are above the "girder system".

The supports from the logs side, which lies below the "beam" will present as a type inclusions of the elastic supports, that applied to the "beam". Relations between the logs that makes up the "beam" will represent as inclusions in elastic stiffness "beam" as a type of elastic joints. They are entered as inclusion in a flexion stiffness dimensional rod of the length of the "beam". Let's assume that the bending stiffness $EI(x)$ is constant within each plot and the same for all plots at $x \neq x_i$ and is equivalent rigidity EI_0, and when $x = x_i$ has singularities. With these inclusions bending moment and shear force are continuous functions of x [5]. The size of a concentrated loads and moments will depend on the number of rows assortments above the “beam” and on the type of “beam”, of which resistance will be considered. Excluding intermediate parameters in inclusions type hinges, the deflections and angles are discontinuous functions, but moments and forces cutting are continuous. Concentrated forces P_i and moments Q_i will reduce to certain arguments and deem them equal value $P_i n_i / n$.

Methodology. Let’s consider a stack of round timber (or in general – stack without pads) as a discrete environment and note the mechanical properties which are inherent in the environment. As is known, the volume of the stack consists of solid volume tangents between a log and the voids between them. Each deck alone, possesses all the properties of solids, and a set of logs forms a discrete environment. Such an environment can perceive external compressive load, create spacer efforts when transferring them in the middle of the environment and distribute internal and external compressive load over a large area within the stack. The ability to pack (stack without pads) perceive the external compressive load indicates that this medium has the properties of solids [6, 7].

Mechanical properties of a packs (stack without pads) are determined by the size, shape and positioning of the logs [7]. Each of these parameters can be random or ordered. And in ordered systems, it is necessary to distinguish neighbor (deterministic) procedure and long-range (random). For example, you can create a model pack (stack without pads) in an ordered system of short-range order, which is formed of the same size cylinders with certain procedures thereof. However, almost likelihood compliance with these conditions is zero because random factors (variations in the sizes of cylinders, the deviation from the correct form, etc.) will change the structure of the environment, depended to a given state. Hence, the parameters of the medium will change, conditions of transfer efforts will change as well as the distribution of pressure within the environment. In this sense, the long-range order of the system will be necessarily random.

In real stacks the distribution of effort within the environment depends on changes in the structure of the environment, which is determined by the size, shape and relative position of individual logs that create this environment. In this regard, the analysis of the determining factors of the environment necessary to the specifics of technological production of round timber in forest depots, as well as existing standards and specifications for equipment distribution by length, diameter, species.

During the research process, capture logs gripping revealed the formation of “beam” as a concomitant process [8, 9], Fig. 1. Levers grips deepened in the stack at a certain depth, then under perform turnaround efforts hydraulic levers. As a result, the logs are moving – they first move to the area of least resistance in the circuit inside the grips and beyond them.

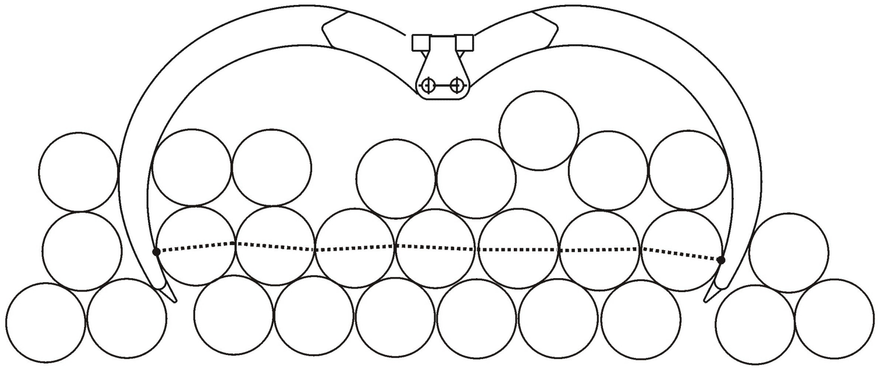

Fig. 1. The process of capturing logs and formation of “beam”

Ground of theoretical bases.

1. Construction of mathematical models for beams of variable section.

Consider the “beam” that is loaded with a distributed load of intensity q, Fig. 2.

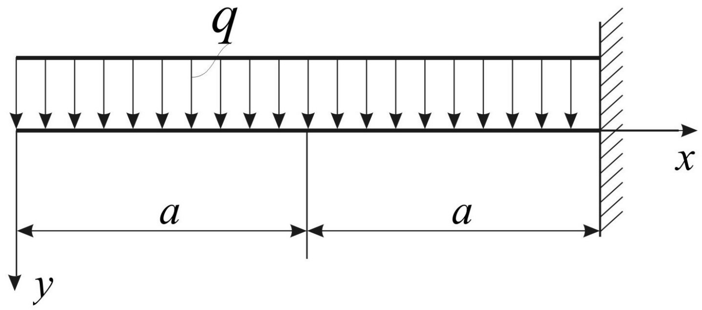

Fig. 2. Scheme of a load of a beams, loaded by the uniformly distributed load

Differential equation curved axis “beam” is following

$$\left[EI(x)\upsilon''\right] = q(x), \tag{1}$$

If we have a variable stiffness core , such as piecewise constant, then

$$EI(x) = EI_0\left[1+\sum_{i=0}^{n}\alpha_i\sigma_0(x-x_i)\right], \tag{2}$$

where EI_0 – stiffness at $0 < x < x_1$; α_i – parameter jump $EI(x)$ at the intersection $x = x_i$.

Perform the differentiation of the left side of the equation, which expresses the intensity of an arbitrary load applied at a point, we obtain

$$\upsilon^{IV} + 2\frac{I'(x)}{I(x)}\upsilon''' + \frac{I''(x)}{I(x)}\upsilon'' = \frac{q(x)}{EI(x)}, \tag{3}$$

Mark $2\frac{I'(x)}{I(x)}\upsilon''' + \frac{I''(x)}{I(x)}\upsilon'' = A$.

If $I(x)$ is jumping into sections $x = a_i$, then $I(x) = I_0\left[1+\sum_{i=0}^{n}\alpha_i\sigma_0(x-a_i)\right]$.

Then
$$A = \sum_{i=1}^{n}\alpha_i\frac{2\upsilon'''\sigma_1(x-a_i)+\upsilon''\sigma_2(x-a_i)}{1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-a_i)}. \tag{4}$$

Bending moments can be expressed in terms of stiffness and second derivative of displacement as:

$$EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-a_i)\right]\upsilon'' = -M(x),$$

so
$$\upsilon'' = \frac{-M(x)}{EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-a_i)\right]}.$$

The third derivative of displacement is expressed through the cutting force and moment as follows

$$\upsilon''' = -\frac{2Q(x)}{EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-a_i)\right]} + \frac{\sum\alpha_i M(x)\sigma_1(x-a_i)}{EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-a_i)\right]^2},$$

Then

$$A=-\sum_{i=1}^{n}\frac{\alpha_i}{EI_0}\frac{2Q(x)\sigma_1(x-a_i)+M(x)\sigma_2(x-a_i)}{\left[1+\sum_{j=1}^{n}\alpha_j\sigma_0(x-a_j)\right]^2}+\sum_{i=1}^{n}\frac{\alpha_i}{EI_0}\frac{M(x)\sigma_1^2(x-a_i)}{\left[1+\sum_{j=1}^{n}\alpha_i\sigma_0(x-a_j)\right]^3}$$

Given that the properties of functions

$$\left[1+\sum_{j=1}^{n}\alpha_j\sigma_0(x-a_j)\right]^{-2}\sigma_1(x-a_i)=\frac{\sigma_1(x-a_i)}{(1+\sum_{j=1}^{i-1}\alpha_j)(1+\sum_{j=1}^{i}\alpha_j)},\tag{5}$$

$$\left[1+\sum_{j=1}^{n}\alpha_j\sigma_0(x-a_i)\right]^{-2}\sigma_2(x-a_i)=\frac{\sigma_2(x-a_i)}{(1+\sum_{j=1}^{i-1}\alpha_j)(1+\sum_{j=1}^{i}\alpha_j)}+$$

$$+2\alpha_j\left[\sum_{j=1}^{n}\alpha_j\sigma_0(x-a_j)\right]^{-3}\sigma_1^2(x-x_i),$$

expression for A takes the form

$$A=-\frac{2Q(x)}{EI_0}\sum_{j=1}^{n}\frac{\alpha_i\sigma_1(x-x_i)}{(1+\sum_{j=1}^{i-1}\alpha_j)(1+\sum_{j=1}^{i}\alpha_j)}-\frac{M(x)}{EI_0}\sum_{i=1}^{n}\frac{\alpha_i\sigma_2(x-x_i)}{(1+\sum_{j=1}^{i-1}\alpha_j)(1+\sum_{j=1}^{i}\alpha_j)}\tag{6}$$

If $Q(x)$ and $M(x)$ is continuous at the points of rigidity jumping x_i from the properties of $\sigma_1(x)=\sigma_0'(x)$ follows

$$Q(x)\sigma_1(x-x_i)=Q(x_i)\sigma_1(x-x_i);$$
$$M(x)\sigma_2(x-x_i)=M(x_i)\sigma_2(x-x_i)-Q(x_i)\sigma_1(x-x_i).$$

Obtain

$$A=-\frac{1}{EI_0}\sum_{i=1}^{n}\frac{\alpha_i\lfloor Q(x_i)\sigma_1(x-x_i)+M(x_i)\sigma_2(x-x_i)\rfloor}{\left(1+\sum_{j=1}^{i-1}\alpha_j\right)\left(1+\sum_{j=1}^{i}\alpha_j\right)}\tag{7}$$

This equation curved axis “beam” compressed by force N, written as

$$EI_0\upsilon^{IV}+\frac{N\upsilon''}{\left[1+\Sigma\alpha_i\sigma_o(x-x_i)\right]}=\frac{q(x)}{1+\sum_{j=1}^{n}\alpha_i\sigma_o(x-x_i)}+$$

$$+\sum_{i=1}^{n}\frac{\alpha_i\lfloor Q(x_i)\sigma_1(x-x_i)+M(x_i)\sigma_2(x-x_i)\rfloor}{\left(1+\sum_{j=1}^{i-1}\alpha_j\right)\left(1+\sum_{j=1}^{n}\alpha_j\right)}.\tag{8}$$

Considering the continuity, instead $M(x_i)$, $Q(x_i)$, we can take either $M(x_i-0)$, $Q(x_i-0)$ or $M(x_i+0)$, $Q(x_i+0)$. Although derivative υ'' breaking, and υ''' has singularities at points $x=x_i$, as $I(x)$ has continuity breaks of the 1st kind

$$Q(x_i-0)=-EI_0\upsilon''(x_i-0)\left(1+\sum_{j=1}^{i-1}\alpha_j\right);\quad Q(x_i-0)=-EI_0\upsilon'''(x_i-0)\left(1+\sum_{j=1}^{i-1}\alpha_j\right).\tag{9}$$

Then equation (7) can be written as

$$\upsilon^{\mathrm{IV}}+\frac{N}{EI_0\left[1+\sum_{j=1}^{n}\alpha_i\sigma_0(x-x_i)\right]}\upsilon''=\frac{q(x)}{EI_0\left[1+\sum_{j=1}^{n}\alpha_i\sigma_0(x-x_i)\right]}-$$

$$-\sum_{i=1}^{n}\frac{\alpha_i}{1+\sum_{j=1}^{i}\alpha_j}\left[\upsilon'''(x_i-0)\,\sigma_1(x-x_i)+\upsilon''(x_i-0)\,\sigma_2(x-x_i)\right] \tag{10}$$

Distributed load intensity $q(x)$ can be represented as

$$q(x)=\sigma_*(x)\left[1+\sum_{i=1}^{n}\beta_i\sigma_0(x-x_i)\right],$$

where $\sigma_*(x)$ – continuous function in points $x=x_i$ (i=1, 2, …, n). Function $q(x)$ has breaks the continuity of the 1st kind, which are determined by the parameters jumps β_i. From the properties of the product of the Heaviside function

$$\left[1+\sum_{i=1}^{n}\beta_i\sigma_o(x-x_i)\right]\left[1+\sum_{j=1}^{n}\alpha_i\sigma_o(x-x_i)\right]^{-1}=1+\sum_{i=1}^{n}\gamma_i\sigma_o(x-x_i),$$

where $$\gamma_i=\left(1+\sum_{i=1}^{i}\beta_i\right)\left(1+\sum_{j=1}^{i}\alpha_j\right)^{-1}-\left(1+\sum_{i=1}^{i-1}\beta_i\right)\left(1+\sum_{j=1}^{i-1}\alpha_i\right)^{-1}.$$

If the intersection point $x=x_i$ applied concentrated forces P_i and moments M_i, then the equation of bending compressed strength "beam" will look

$$\upsilon^{\mathrm{IV}}+\frac{N\upsilon''}{EI\left[1+\sum_{j=1}^{i}\alpha_j\sigma_0(x-x_j)\right]}=\sum_{i=1}^{n}\frac{P_i\sigma_1(x-x_{i-0})+M_i\sigma_2(x-x_{i-0})}{\left[1+\sum_{j=1}^{n}\alpha_i\sigma_o(x-x_i)\right]}-$$

$$-\sum_{i=1}^{n}\frac{\alpha_i\left[\upsilon'''(x_i-0)\sigma_1(x-x_i)+\upsilon''(x_i-0)\sigma_2(x-x_i)\right]}{1+\sum_{j=1}^{i}\alpha_j}+\frac{\sigma_*(x)}{EI}\left[1+\sum_{i=1}^{n}\gamma_i\sigma_0(x-x_i)\right]. \tag{11}$$

If $\sigma_*(x)=0$, then equation (11) is written

$$\upsilon^{\mathrm{IV}}+\frac{N\upsilon''}{EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_o(x-x_i)\right]}=\frac{1}{EI_0}\sum_{i=1}^{n}\left[\frac{P_i\sigma_1(x-x_i)}{\left(1+\sum_{j=1}^{i}\alpha_j\right)}+\frac{M_i\sigma_2(x-x_i)}{\left(1+\sum_{j=1}^{i}\alpha_j\right)}\right]-$$

$$-\sum_{i=1}^{n}\frac{\alpha_i}{1+\sum_{j=1}^{i}\alpha_j}\left[\upsilon'''(x-0)\sigma_1(x-x_i)+\upsilon''(x_i-0)\sigma_2(x-x_i)\right]. \tag{12}$$

Thus, we get an equation of a variable stiffness "beam" with the expose of the compressing forces N and concentrated at the points x_i of forces and moments.

2. Inclusion in the stiffness of the base.

Let's consider elastic supports, which may resist vertical movement section and the elastic ties that resist rotation section. These links are considered as inclusion in the stiffness of the elastic foundation, Fig. 3.

If the variable section "beam" is on elastic foundation, then it has applied not only distributed load of intensity $q(x)=-k_1(x)\upsilon(x)$, but shared moments of intensity $m(x)=-K_2(x)\upsilon'(x)$, where $K_1(x)$ and $K_2(x)$ variables of base, and $\upsilon(x)$ – deflection at the intersection x, $\upsilon'(x)$ – angle of this intersection. Further, the model assumes that the intensity of the moments $m(x)>0$, if the direction of rotation clockwise moment $q(x)>0$, if the direction of the load from the top down, taking into account

$$M'_x = Q(x) + m(x),\ Q'_x = -q(x),\quad M''_x = -q(x) + m'(x). \tag{13}$$

Differential equation curved axis "beam" which forces compressed, looks

$$\left[EI(x)\upsilon''\right]'' + N\upsilon'' = q(x) - m'(x). \tag{14}$$

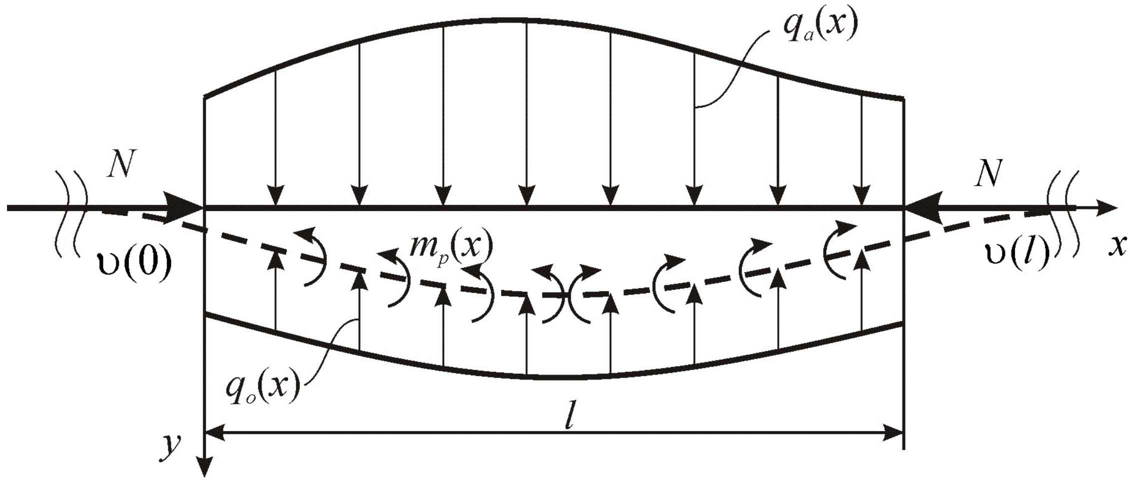

Fig. 3. Scheme included in the stiffness of the elastic foundation

If the intensity of the resistive load equal $q_a(x)$, then

$$q(x) = q_a(x) + q_p = q_a(x) - K_1(x)\upsilon(x), \tag{15}$$

$$m(x) = -K_2(x)\ \upsilon'(x)$$

differential equation curved axis "beam", that compressed force N has the form

$$\left[EI(x)\upsilon''\right]'' + N\upsilon'' - \left[K_2(x)\upsilon'(x)\right]' + K_1(x)\upsilon(x) = q_a(x) \tag{16}$$

where

$$q_a(x) = \sum_{i=1}^{n} P_i\sigma_1(x - x_i) + \sum_{j=1}^{n_1} M_j\sigma_2(x - x_j).$$

Let's consider focusing inclusion into a stiffness base. When the most solid foundation is absent, then

$$K_1(x) = \sum_{i=1}^{n} K_{1i}\sigma_1(x - x_i),\quad K_2(x) = \sum_{i=1}^{n} K_{2i}\sigma_2(x - x_i) \tag{17}$$

K_{2i} – stiffness of the elastic connection, which is equal to the reaction moment at $\upsilon'(x_i) = 1$.

Given the continuity angle υ'_x

$$\left[K_2(x)\upsilon'(x)\right]'_x = \left[\upsilon'\sum_{i=1}^{n} K_{2i}\sigma_1(x - x_i)\right]'_x = \sum_{i=1}^{n} K_{2i}\upsilon'(x_i)\,\sigma_2(x - x_i) \tag{18}$$

and continuity of movement υ_x

$$K_1(x)\ \upsilon(x) = \sum_{i=1}^{n} K_{1i}\upsilon(x_i)\ \sigma_1(x - x_i),$$

obtain the equation

$$\left[EI_0\upsilon''\right]'' + N\upsilon'' - \sum_{i=1}^{n} K_{2i}\upsilon'(x_i)\ \sigma_2(x - x_i) + \sum_{i=1}^{n} K_{1i}\upsilon(x_i)\ \sigma_1(x - x_i) = q_a(x). \tag{19}$$

For variable section rod bending equation takes the form

$$\upsilon^{\mathrm{IV}}+\frac{N\upsilon''}{EI_0\left[1+\sum_{i=1}^{n}\alpha_i\sigma_0(x-x_i)\right]}=\frac{1}{EI_0}\sum_{i=1}^{n}\left[\frac{P_i\sigma_1(x-x_i)}{\left(1+\sum_{j=1}^{i}\alpha_i\right)}+\frac{M_i\sigma_2(x-x_i)}{\left(1+\sum_{j=1}^{i}\alpha_i\right)}\right]-$$

$$-\sum_{i=1}^{n}\frac{\left[\alpha_i\upsilon'''(x_i-0)+K_{1i}\upsilon(x_i)\right]\sigma_1(x-x_i)+\left[\alpha_i\upsilon''(x_i-0)-K_{2i}\upsilon'(x_i)\right]\sigma_2(x-x_i)}{\left(1+\sum_{j=1}^{i}\alpha_j\right)}. \quad (20)$$

As a result, we obtain the equation of bending of a variable section "beam" compressed with a forces N, loaded thus led forces P_i and moments M_i to a certain location. They represent the effect on the "beam" resultant forces of gravity and moments of logs on top "beam" and concentrated elastic supports, caused by the action of the "beam" of logs, which are located below the "beam".

Conclusions. Based on the developed models, getting an equation of bending "beam system" with inclusions in elastic foundation distributed hardness and with loads such as concentrated forces and moments. This equation is fundamental for a disquisition of buckling beam system, which is compressed by N.

Note that with the numbering of points of irregularities, the point of the forces and moments do not coincide with points jumping rigidity of a "beams".

We will distinguish concentrated inclusion stiffness foundations and flexion stiffness "beams". Generalized functions will also apply here to get the line deflection of a single analytical expression, regardless to the type of inclusion.

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УДК 630*848:621.86 *Доц. Б.Я. Бакай, канд. техн. наук – НЛТУ України*

Побудова математичної моделі стійкості пачки круглих лісоматеріалів під час процесу переміщення мобільними машинами

Розглянуто питання взаємодії круглих лісоматеріалів під час процесу їх захоплення важелями захоплювача мобільних лісоскладських машинами. Побудовано рівняння згину "балкової системи" з включеннями в пружну основу, розподілену жорсткість, а також з навантаженнями типу зосереджених сил. Для введення зосереджених включень в аналітичні вирази розподілених параметрів використано сингулярні функції.

Ключеві слова: круглі лісоматеріали; захоплювач; взаємодія; мобільні лісоскладські машинами; сингулярні функції.

UDC 674.815. ***Post-graduate I.Z. Pylypiv – UNFU***

EFFECT OF MOISTURE WOOD-FIBER BOARD ON THE PROCESS OF BENDING

Analyzed the results of studies the impact moisture on the radius of bending plates different thickness after applying PVA glue on one and two sides with different exposure time. Found that for all thicknesses of both unilateral and bilateral moistening occurs optimal exposure time after applying the adhesive to the bending process. The study allowed us to obtain the minimum values of radius for each thickness of plates at one and two sided moisture.

Keywords: fiberboard, curved elements, thickness of plates, bending, moisture, PVA glue.

One way of making curved elements in the manufacture of furniture and wood products may be bending their formation several sheets of wood-fiber board. Since bent glued elements are formed as a result of bending and gluing a number of plates, the question depending on the minimum bending radius of the plates on their thickness, moisture boards with glue and time exposure after gluing before bending. To understand these relationships, a series of experimental studies. Investigated wood-fiber plates of thickness 2.5 mm, 3.2 mm, 4.0 mm, 5.0 mm, 6.0 mm produced by PJSC Fanplit (Kiev). The minimal radius is determined for unilateral and bilateral humidification PVA glue with an exposure time of 2 to 10 minutes, with an interval of 2 minutes. Experimental studies were carried out according to the method presented in article [1]. Number of duplicate experiments was n = 30 ... 50. As a result of statistical analysis of experimental results obtained average values of the minimum permissible bending radius R_{me}, the variance of the value of D and established the law of its distribution, the values of the random (normal). Summarized results are shown in Table. 1 and illustrated in Fig. 1. Analysis of the results leads to the following conclusions:

Table 1. Mean and variance of the minimum permissible bending radius R_{med}, mm

Number of parties dampening adhesive	Duration of exposure, min	Plate thickness, mm									
		2,5		3,2		4,0		5,0		6,0	
		med.	var.	med.	var.	med.	var.	med.	var.	med.	var.
1	2	72,8	20,94	92,7	21,94	148,3	11,18	172,6	13,68	247,4	13,96
	4	67,1	19,67	87,1	20,71	142,1	19,74	168,3	11,71	244,1	12,34
	6	62,2	22,62	83,2	36,66	134,6	18,04	163,8	15,38	240,4	20,79
	8	64,4	23,97	84,4	24,51	138,5	15,63	166,9	13,23	242,2	10,28
	10	67,0	19,75	86,6	20,30	141,5	10,18	170,6	13,28	244,8	11,82
2	2	67,1	19,67	83,5	22,32	130,9	10,75	160,3	12,21	237,9	13,84
	4	60,8	25,61	77,2	21,06	123,8	11,90	155,0	14,37	234,1	15,67
	6	53,3	34,61	72,9	30,20	114,7	12,02	150,1	17,91	230,2	21,45
	8	57,4	26,93	74,4	23,56	117,8	10,16	152,7	15,16	232,9	14,64
	10	61,6	18,52	76,9	19,65	122,0	9,72	155,7	22,35	235,2	12,71

1. Wetting surfaces wood-fiber board PVA glue to reduce the minimum allowable bending radii. This is particularly noticeable for plates of small thickness (2.5 mm). In bilateral gluing value of the minimum permissible radius can be reduced by 5 ... 15%, depending on the thickness of the plates. 2. For all thicknesses of plates, as in one - and bilateral moisture observed effective exposure time of 6.5 ... 7 min at which the value of the minimum permissible radius reaches an extremum (minimum). Found that the dependence of the average values of the minimum permissible bending radii depending on the exposure time can be approximated by a mathematical relationship in the form of a second order polynomial: $R_{min} = aT^2 - bT + c$.

General view of the dependence holds for all investigated thicknesses of plates for one - and bilateral humidity. Differentiation obtained dependences dR_{min}/dT allowed to get value T_{opt} exposure time at which the minimum allowable bending radius reach extremum. The results are kept in the Table 2. From the results we can assume that the optimal exposure time after applying the adhesive must be T_{opt} = 6.7 min. Regardless of the number of parties moisture and thickness of plates. The coefficients of the mathematical model ***a*** and ***b*** do not depend on the thickness of the plates, however, greatly affect the value of the coefficient ***c*** thickness of plates and therefore the value of R_{min} (Fig. 2).

Table 2. The results of the mathematical description the minimum permissible bending radius of exposure time ($R_{min}=aT^2-bT+c$)

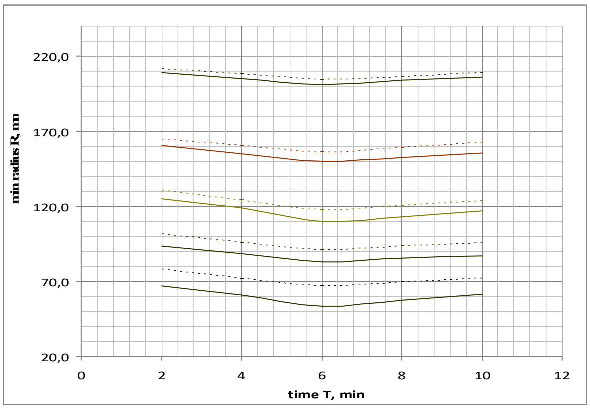

Fig. 1. Dependence of changes in the mean values of minimum permissible bending radius of exposure time (---- unilateral moisture glue —— bilateral moisture glue)

Thickness of plate, mm	Moisturize one side					Moisturize two sides				
	coefficients			T_{opt}	R_{min}	coefficients			T_{opt}	R_{min}
	a	b	c			a	b	c		
1	2	3	4	5	6	7	8	9	10	11
2.5	0.42	-5.78	83.7	6.8	63.9	0.58	-7.71	80.6	6.6	55.0
3.2	0.42	-5.70	104.7	6.9	85.4	0.37	-5.26	92.7	7.07	74.0
4.0	0.50	-6.90	158.4	6.86	134.2	0.58	-8.03	142.5	6.95	115.7
5.0	0.42	-5.32	180.8	6.30	164.1	0.49	-5.72	164.2	6.67	150.1
6.0	0.31	-4.07	218.55	6.57	205.20	0.34	-4.34	216.41	6.48	202.44

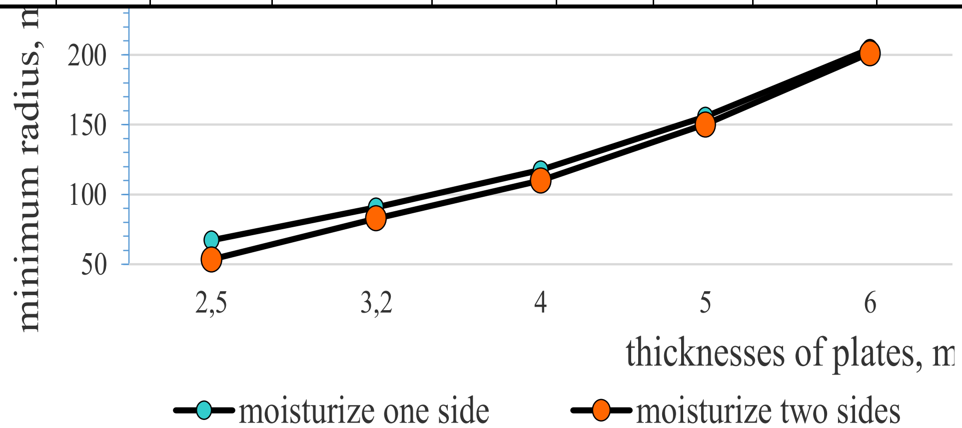

Fig. 2. Dependence of the minimum radius for different thicknesses of plates

Because, the formation of the package in the manufacture of curved elements to consider bending radius and depending on it to select the thickness of plates.

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УДК 674.815. ***Аспір. І.З. Пилипів – НЛТУ України***

Вплив зволоження деревинно-волокнистих плит на процес їх гнуття

Проаналізовано результати досліджень впливу вологи на значення радіуса гнуття плит різної товщини після нанесення клею ПВА на одну та дві сторони із різною витримкою у часі. Встановлено, що для усіх товщин як з однобічним так і двобічним зволоженням має місце оптимальне значення часу витримки після нанесення клею перед процесом гнуття. Дослідження дозволило отримати мінімальні значення радіусів для кожної із товщин плит при одно та двобічному зволоженні.

Ключові слова: ДВП, гнуті елементи, товщина плити, гнуття, волога, клей ПВА.

UDC 657.6:504 *Prof. S.I. Lebedevych – UNFU*

ORGANIZATIONAL AND ECONOMIC MECHANISM OF SHAPING THE SYSTEM OF INTERNAL ENVIRONMENTAL AUDIT

The article underlines the need for shaping the system of internal environmental audit in businesses as being a topical issue. A science-based definition of the internal environmental audit has been proposed. Also presented here are the classification of techniques for the internal environmental audit and models of its planning and conducting.

Keywords: organizational and economic mechanism, system, internal environmental audit, classification, techniques, model, process, planning.

Introduction. In the 1970s, a need arose for the assessment of enterprises economic activities in a number of countries in Europe and North America, from the standpoint of their compliance with the existing environmental legislation. This kind of assessment was termed as the "environmental audit". While originally being an instrument of environmental legislation enforcement, in the 21th century this has evolved into the economic-and-legal instrument to encourage the environmental protection activities of enterprises in order to enhance their investment attractiveness[1]. **Problem formulation.** According to the Law of Ukraine "On Environmental audit" [2] the environmental audit is classified into "internal" and "external". This division of the environmental audit is similar to that of general audit (Financial audit). The Law [2] and the current EN ISO 1400 and 1900 series do not have adequate definiteness as to the internal environmental audit. This subject has not received proper attention in research works either. This is why of urgent importance is now the problem of developing and realizing the organizational-and-economic mechanism for shaping the internal environmental audit at enterprises. **Results and discussion.** A special-purpose theoretical study into the problem has been conducted by involving a number of enterprises of Ukraine's forest sector [1, 3]. A thorough analysis of the current regulations and the review of the existing monographic literature allowed the following definition [1]: "The internal environmental audit is an independent and fair analytical and consultancy activities aimed at ensuring an optimal level of cumulative environmental and economic effect of nature-use by a given enterprise". The proposed definition allows for practical implementation of the internal environmental audit. The internal environmental audit techniques are of a great variety. Their applications, to our mind, are governed not only by the specificity of an object under auditing but professional level and experience of auditor as well (Table. 1).

Table. 1. Classification of internal environmental audit techniques

Techniques of internal environmental audit		
general scientific	documentary	actual
• Analysis, synthesis • Deduction, induction • a systematic approach • economic and mathematical modeling	• formal verification • arithmetic test, analogy • analytical test • counter test of documents • examination of documents	• inventory, observation • test, laboratory analysis • quick assessment • control scaling of the work performed

The aim of the internal environmental audit is to maximize environmental and economic efficiency of business activities. In our opinion, it should be conducted as follows (Fig. 1):

Stages of internal environmental audit
- Audit planning
- Collection of environmental and audit evidence
- Evaluation of the adequacy of the environmental management system
- Final conclusions and recommendations (preparation of report)

Fig. 1. Model of internal environmental audit

The internal environmental audit of businesses aims at environmental and economic assessing their activities. The relationship between business environmental goals and businesses objectives of their internal environmental audit is shown in Fig. 2.

General model of planning internal environmental audit is shown in Fig. 3.

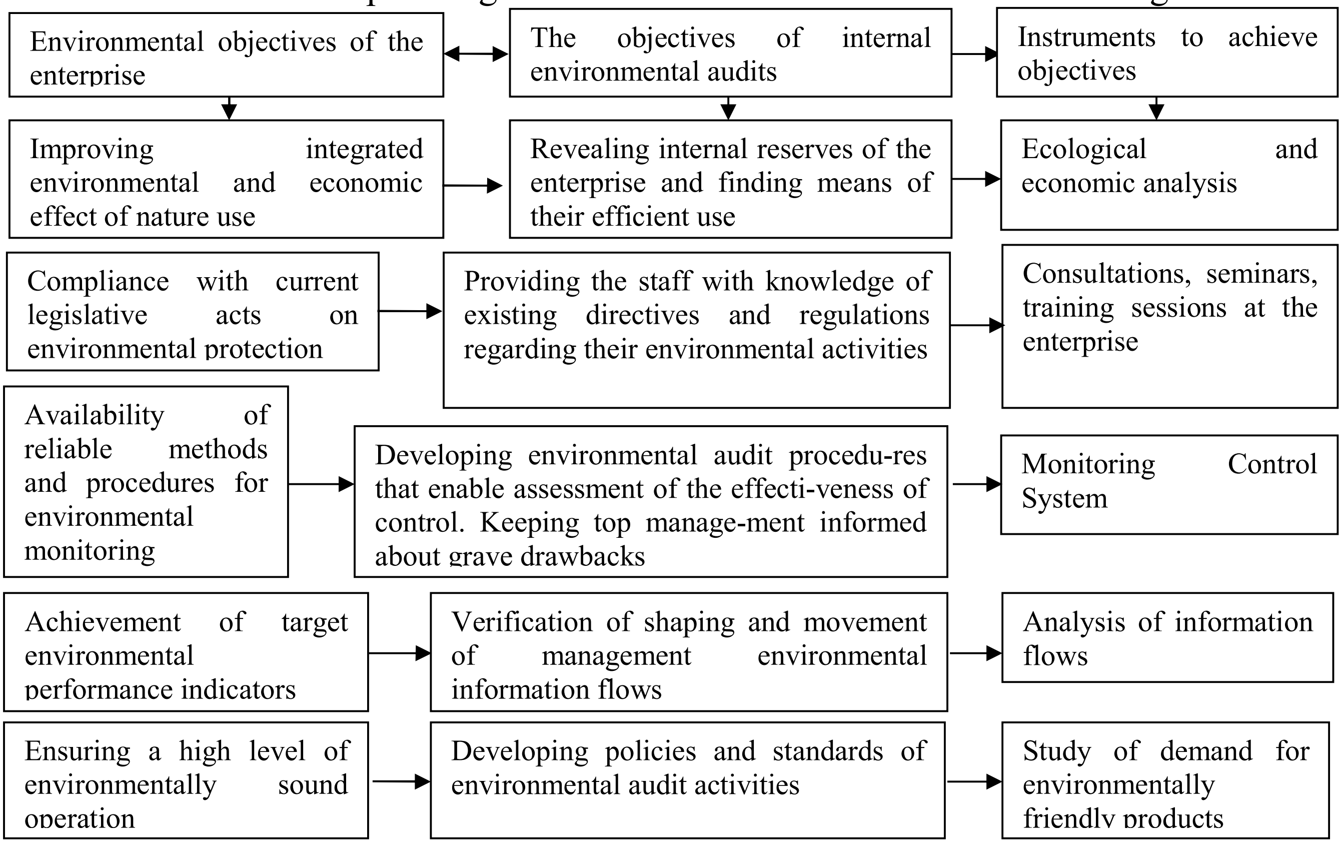

Fig. 2. Relationship of environmental goals with business objectives of their internal environmental audit

Conclusions. Based on the results from our study, we propose here the organizational and economic mechanism for shaping the system of internal environmental audit, which would provide a means of developing specific techniques for introducing the environmental audits in sectoral system of enterprises environmental management in particular to implement economic and mathematical modeling and optimization of the process of businesses environmental audit.

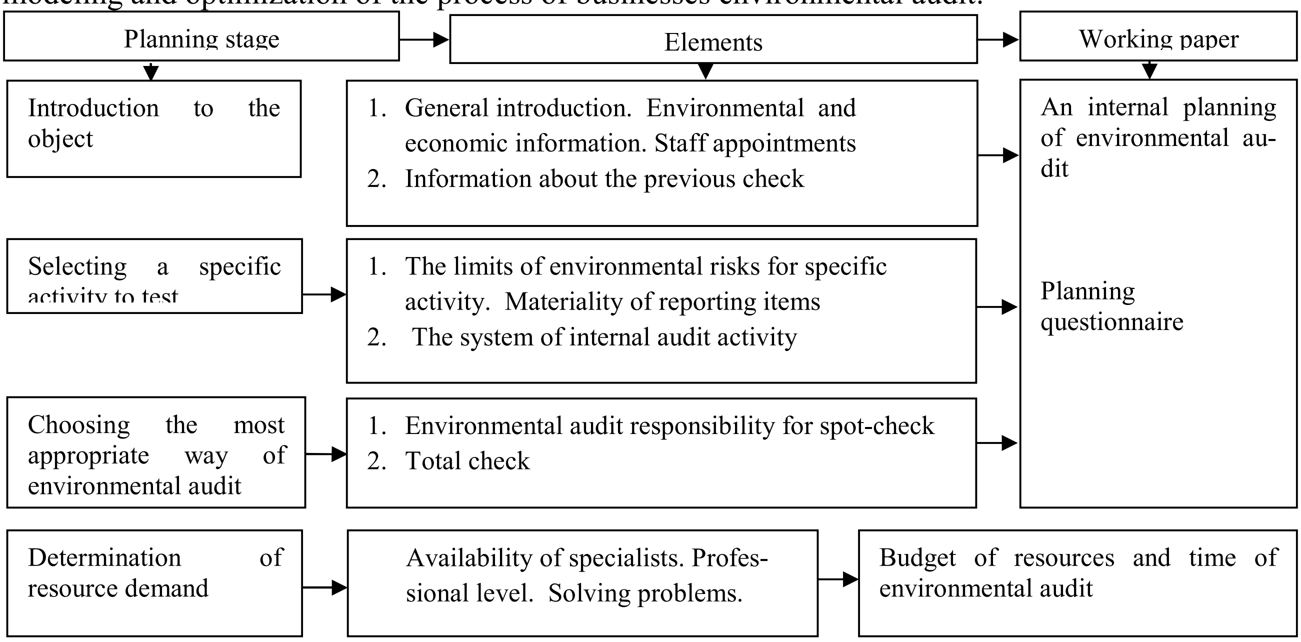

Fig. 3. Model of planning internal environmental audit

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УДК 657.6:504

Проф. С.І. Лебедевич, д-р екон. наук – НЛТУ України

Організаційно-економічний механізм формування системи внутрішнього екоаудиту

Зазначена актуальність формування системи внутрішнього екологічного аудиту підприємств у зв'язку з тим, що Закон України "Про екологічний аудит" та чинне ДСТУ ISO14000 і 19000 не надають адекватного визначення внутрішнього екоаудиту. Запропоновано таке визначення: " Внутрішній екологічний аудит – це незалежна та об'єктивна аналітично-консультаціна діяльність, спрямована на забезпечення належного рівня інтегрального еколого-економічного ефекту природокористування на даному підприємстві". Розроблені класифікація методичних прийомів внутрішнього екоаудиту та модель цього процесу. Узгоджено взаємозв'язок цілей екологічної діяльності підприємств з цілями їх внутрішнього екоаудиту. Розроблено модель процесу планування внутрішнього екоаудиту. Таким чином, в результаті дослідження запропоновано організаційно-економічний механізм формування системи внутрішнього екологічного аудиту, який дає можливість перейти до розроблення конкретних методик впровадження екоаудиту в галузеву систему екоменеджменту підприємств, зокрема здійснити економіко-математичне моделювання і оптимізацію процесу екологічного аудиту підприємств.

Ключові слова: організаційно-економічний механізм, система, внутрішній екологічний аудит, класифікація, методичні прийоми, модель, процес, планування.

UDC 339.9.24
Prof. A.V. Cherep, competitor N.V. Pavlenko – Zaporizhian National University

THE SIGNIFICANCE AND ROLE OF INTERNATIONAL INTEGRATION PROCESSES

The determination of the essence of the international integration process is researched by scientists in the field of economics. The main advantages and disadvantages of the essence as well as the influence of integration processes on the economies of separate countries are determined. The necessity of strengthening and further development of international integration is revealed. The role of integration processes is pointed out.
Keywords: integration, market economy, international relations, world economy, globalization, international organization.

Statement of the problem. The major sign of today's reality is intensive development of integration processes at different levels. The problem of supervision and administration of the global economic processes, which became independent and uncontrolled, arises. The world economy requires uniform performance standards and principles. For the purpose of developing conception approaches to the management of economy, it is necessary to realize the state of economic integration and its estimation by prominent experts.

Analysis of the researches and publications on the problem. While studying the economic essence of integration processes the authors started from the scientific research of this problem by both Ukrainian experts, namely, the works by M. Kizim [1], T. Sylin [2], and by foreign scientists: G. Soros [3], K. Polanyi [4], S. Karaganov [5], J. Meade [6], P. Engelhard [7]. The theoretical grounds of an economic integration process necessity in countries with market economy were proposed as early as in the 1870s-1880s by the representatives of the German historical school – F. List, G. Schmoller, W. Roscher and others. In the 1950s-1960s the problems of economic integration were researched by P. Robson, A. Rugman, A. Philip, R. Cooper, B. Balassa [8] and many others. However, the scientists' research should be thoroughly reviewed in order to reveal the contemporary state of international integration.

Article problem statement. The purpose of the article is determination of the essence, necessity and role of international economic integration.

Statement of basic material of the research. The characteristic feature of the modern stage of the world economy development is international economic integration. In the early XXI century it became a powerful instrument of accelerated development of regional economies and of increase in their competitiveness in the world market. International economic integration is an objective, purposeful, directed process of rapprochement, mutual adjustment and merger of national economic systems which possess the potential of self-regulation and self-development. The expansion of business beyond national borders by creating multinational corporations, globalizing different professional activities as well as necessity for institutialization of the world economy constitute the realities of the existing integration processes nowadays.

TheNeo-Keynesian direction of the theory of international integration is represented in the conception of dirigisme (A. Philip, R. Cooper, etc.). The main problem of regional economic integration is search for optimal combination of economic policy national programs while providing the advantages given by a close economic cooperation. However, integration programs require establishing supranational administration bodies but not every integration subject always agrees to that.

The followers of another theory (P. Robson, A. Rugman) consider that countries head for integration of their economies for the purpose of overcoming the "factor of limitedness" (resources of fuel and production). It is considered that this factor assisted an increase in the production scales, development of commodity differentiation and new technologies. The supporters of another approach consider that establishment of the integrated system enables to set a common goal and jointly achieve it (increase of employment, production, social stability, etc.). Thus the role of the state in settling common problems within the framework of the integrated system increases.

A classical attempt to determine the effects of establishing and rejecting trade within the framework of the EU was made by the American scientist B. Balassa in 1974. He compared the elasticity of demand for imports of the EU countries before the establishment of the integration union and after the EU formation by industries using the same index. In accordance with the results obtained, the formation of the EU effected the trade execution in substantial amounts. While before the establishment of the EU every 1 % of the GDP increase resulted in the increase of trade between the countries by 2.4 %, after the establishment of the EU it accounted for 2.7 %. The effect of rejecting the trade was only observed in separate industries (foodstuff, drinks, tobacco, chemical goods) [8].

The English-American scientist Karl Polanyi studied the issue of economic integration in his works. Karl Polanyi considered that the world economy was a component part of a wider social system. According to him, integration begins with establishing the relations at the level of separate companies. These relations should be mutually beneficial. It results in emerging self-regulated markets. For these markets to develop, it is necessary that the states cease interfering into the world economy [4].

Karl Polanyi, the author of *Great Transformation*, marked that it was government regulation that enhanced economic instability in the global society. The scientist also specified the significance of struggle for the transparency of the world economy.

In our opinion, the absence of government supervision should accelerate integration in the world but this process must be directed and supervised constantly; it stipulates the establishment of special institutes.

J. Meade, a prominent British economist, specified an increase in the role of states in the world market economy. He was a supporter of state regulation of internal processes which influenced a country's foreign economic policy: restrictions on imports for maintaining the international balance of payment. In his work *Trade and Welfare* he stated the influence of international trade on welfare of the countries which did not have competitive internal markets. Grounding on the theory of the "second best", he showed that, if the terms necessary for reaching the optimal position cannot be implemented, the observance of the free trade direction can be destructive and can decrease welfare. Moreover, in case of imposing high trade barriers, "better" can be the enemy of "good": in this case restrictions on trade can assist an increase in the level of economic welfare [6].

P. Engelhard, a French economist, considered that the international economic integration is necessary to overcome a row of global problems but there are "lines of discontinuity", which hinder this process. They are as follows:

- between the leading post-industrial states and other states;
- between wealthy and poor societies;
- between the Muslim world and the West [7].

At the same time P. Engelhard asserts that integration is only economically beneficial to the "system countries". Supranational transnational structures are able to deprive any country of its national income including it into the global one and to distribute it among a small number of developed countries [9].

Proceeding from the stated above, we can draw the conclusion that for most countries integration does not solve the problem of economic growth.

George Soros, an American financier studied the issue of financial markets integration as well. He considers that under the effect of integration separate countries must diminish the role of the state in economy in order to increase their competitiveness. According to G. Soros, integration has brought enormous benefits. State interference into economy has never been very effective; in addition, the state is inclined to misuse power. Integration has revealed new opportunities for innovation and business to people and accelerated the global economic growth. But there are negative aspects in the world integration. Firstly, it is disposed to crises; secondly, it deepens inequality between the rich and the poor both inside the countries and internationally; thirdly, it causes the misdistribution of resources between private and state interests [3].

G. Soros states that integration forced separate countries to promote the efficiency of state administration or, at least, restrict the role of the state in economy. But integration has made the world more interdependent; ineffective state administration is an obstacle on the way to a properly functioning global society. In the opinion of G. Soros, it would be better to correct the faults revealed than to kill the goose that laid the golden eggs [3].

Like P. Engelhard G. Soros considers that global financial markets bring benefits to the countries which are in the center of the international market system, especially the USA. Financial markets absorb greater part of savings and incomes made in the entire world, transfer them to the centre, from where they are again transferred to the periphery either directly through financial instruments like shares and bonds or indirectly through multinational corporations [9].

Thus we can conclude that central countries receive the lion's share of all the profits. Nevertheless, G. Soros thinks that it does not mean that the periphery countries cannot profit from the international division of labour and international allocation of capital. But the rest of the countries become even more dependent on the developed countries.

S. Karaganov, a Russian economist asserts that integration diminishes the possibility of applying the economic levers of influence on the world economy. S. Karaganov states that the global financial flows affected by integration processes are beyond the national and international regulations. According to the scientist, the world needs global management, "world administration".

In his work *The Contradiction of Contradictions,* S. Karaganov states that to overcome the global chaos of the world economy, it is necessary to provide and create a new systematic global administration. In his opinion, the UNO is an organization which exists only for dialogs, not for settling problems [5].

Conclusions. Proceeding from the above-mentioned, we can draw the conclusion that the prominent economists of the world are involved in studying the issue of international economic integration. The scientists' opinions coincide in the following:

- economic integration is a ponderable and progressive process;
- the process of integration is not regulated today;
- institualization is necessary for providing welfare and stability in the world economy;
- the role of the state in the world economy is diminishing substantially.

In our opinion, the issue of economic integration must be investigated for the purpose of providing the economy competitiveness of our own state.

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УДК 339.9.24

Проф. А.В. Череп, д-р екон. наук;
здобувач Н.В. Павленко – Запорізький національний університет

Значення та роль міжнародних інтеграційних процесів

Досліджено визначення сутності процесу міжнародної інтеграції вченими-економістами. Визначено її основні переваги і недоліки, а також вплив інтеграційних процесів на економіки окремих країн. Встановлено необхідність посилення та подальшого розвитку міжнародної інтеграції. Зазначено роль інтеграційних процесів.

Ключові слова: інтеграція, економічні процеси, міжнародна інтеграція, світова економіка, глобалізація, міжнародна організація.

UDC 339.187:684

Assoc. prof. A.V. Ivanusa – UNFU;
assoc. prof. V.B. Zagornyak – PHEI IMNR UEL «KROK»

ECOLOGICAL ASPECTS OF FORMATION OF MARKETING STRATEGIES FOR FURNITURE ENTERPRISES

Presented are the basic components of the marketing strategy of furniture enterprises in the context of ecological and economic characteristics of furniture manufacturing and furniture products. Analyzed were furniture products and ecological of aspects the main components of the marketing strategy of the furniture business: product, place, price, promotion, positioning.

Keywords: marketing strategy, marketing strategy components, furniture, furniture enterprise.

Problem. The formation and improvement of market relations, as well as continuous growth of competition, particularly in critical conditions of management, stipulates the necessity constant monitoring and improvement of all elements of production and economic activity of enterprise. One of the major components that has a significant impact on the efficiency of each enterprise is its marketing strategy. It determines the pattern of behavior on the market, and therefore determines the level of perception of the environment and the establishment of dynamic equilibrium with it. In the modern conditions of managing are observed tendencies toward continuous growth of so-called «environmentally sensitive» markets, when consumers choosing products, pay much attention to its ecological parameters. That is why the development and implementation of marketing strategy, based on a complex account system of ecological aspects of production, sale and promotion of products to the consumer is pressing and important question at the present stage of development of national economy of the country.

The results of the study. Marketing strategy – marketing activities of the company for sustainable promotion of their products on the market, including setting goals, analysis, planning marketing activities, monitoring [1, p. 377]. By definition, U.S. the research share of marketing strategies in the overall strategy of the company is about 80 % [6]. Among a disparate elements that define the features of a marketing strategy of the enterprise to provide basic, primary components that can be represented in the form of so-called «five P Marketing» are as follows: 1. Goods and Services (Product) – give the seller something that has value. They should draw attention to seller by its usefulness compared to competitors. 2. Place or distribution system (Place) – delivery of goods (services) to consumers in the right place at the right time. 3. Price (Price) – that the buyer agrees to pay in exchange for goods. 4. Promotion (Promotion) communicates to the buyer information about the product and makes him decide to purchase. 5. Positioning (Positioning) occurs when a product is compared with similar deals. Successful positioning means that this product will be given preference to products of competitors. In the context of the above elements, we analyze the relevant elements of the marketing strategy of furniture enterprises with emphasis placed on its ecological components.

1. Goods and Services (*Product).* Products of furniture making, which is focused on the end consumer, is polytypic furniture, which, according to the National Classifier of Ukraine, are divided into separate groups (Table 1). Based on research of the Institute of Human Ecology, Academy of Medical Sciences of the Russian Federation, one could argue that in an ordinary apartment with furniture may be present by about 100-150 types of chemicals, including dangerous substances such as aerosols lead, cadmium, mercury, copper, zinc, styrene , benzol, phenol, formaldehyde, etc [2]. This results in vapor of varnish and paint, furniture glue used in the manufacture of chipboard binder components, decomposition products of polymeric materials and more. It is one of the important tasks of furniture industry, not only the maximum satisfaction of consumer needs for high quality products, but, first of all ensuring its sustainable development with the gradual minimization of negative impact on the environment and human health. Practice the principle of sustainable development of furniture manufacturing requires, in our opinion, the transformation of existing technological processes according to ecological standards and systematic realization of such basic approaches [2]: ecologization of construction materials, finishing materials and ecologization of glues, reuse of wood from old furniture.

2. Place or distribution system (Place). An important aspect of the distribution system of furniture products for «ecologically sensitive» markets is the principle of clean commodity circulation, in particular, the use of ecologically acceptable vehicles that would ensure minimal destructive impact on the environment. For example, consider furniture made in Indonesia from ecologically clean wood («green»), if they spend a lot of transportation fuel on, the result is significant environmental pollution [5]. For this reason, the requirement of ecologically conscious consumers for furniture production is the availability of the certificate of origin. There are several international schemes that deal with certification. One of them – FSC. FSC-chain – information about the path that passes forest Products of wood, or recycled materials, from the processing to the consumer, including all consecutive stages of processing, transportation, manufacturing, storage and distribution, where the transition from one stage of the supply chain to the other involves change of the owner [3].

Table 1. Classification of types of products of furniture making according to the National Classifier of Ukraine

Code	Product Name
36.11.11	Furniture for seating special (preferably with a metal frame) units.
36.11.12	Furniture for seating (preferably with a wooden frame) units.
36.11.13	Furniture for seating other items.
36.12.10	Furniture clerical (office) and for commercial establishments, units
36.12.11	Furniture clerical (office) metal pieces.
36.12.12	Furniture clerical (office) wooden, pieces.
36.12.13	Furniture, for commercial timber, pieces.
36.13.10	Furniture for kitchen, pieces.
36.14.10	Metal furniture, pieces.
36.14.11	Wooden interior furnishings for residential, units.
36.14.12	Furniture made of wood, pieces.
36.14.14	Furniture of plastics and other materials (including cane, osier, bamboo and similar materials) unit.
36.15.11	Frames, mattresses, unit.
36.15.12	Mattresses, items.

3. Price (Price). A significant feature of the pricing segment is, in our view, diversification of prices on the principle of separation of functions: presentational prices – wholesale prices, retail prices. Each of these groups has its purpose and determines the possibility of adjusting pricing policy in accordance with the features of cooperation with each client, in particular. This is, obviously, an important criterion in the formation of brand («Brand») under the furniture product requirements «green», which makes pricing policy connected with the principle of ecologically clean production.

4. Promotion (Promotion). Promotion of furniture products, including the «ecologically sensitive» markets stipulates the necessity of a two-way communication of information between businesses and consumers that allows you to discover and prove a set of features and the level of ecological acceptability confirmed with corresponding certificates. For example, the results of the study «Ecological awareness in Germany 2004», held by the Ministry of Environment of Germany, one could argue that 13% of Germans know about the marking of FSC, including 78% focus on its availability when buying goods. The research showed that for 92% of respondents, environmental issues are essential [3].

5. Positioning (Positioning). The growth of «ecological consciousness» evokes the need for special positioning of the enterprise and building its environmental policies, which often may contain certain conceptual approaches to environmental protection. For example, the Danish company Jysk Holdin, has successfully positioned itself as a «green», trying to embody the concept of environmental protection [4]:

- to spread products of wood origin, including furniture from solid wood certified by the FSC system and invest resources in a system of forest certification through FSC Tropical Forest Trust (TFT);
- to sell only those fabrics that correspond to highest criteria and standards that are even more stringent than national standards (eg Ekotex 100);
- to observe the smallest components of ecological standards in each country in which it operates;
- to ensure in its activity the process of reducing the use of polyvinyl chloride (PVC);
- to provide continuous recycling – recycling utilization of resources in the company structure.

Jysk Holdin, positioning itself as a «green company» interacts with many organizations, including such as the Tropical Forest Trust, Smart Wood and others.

Conclusion. With a systematic analysis of each of the above components, conducted in the context of ecological and economic features of furniture manufacturing functioning, you can create an effective marketing strategy for every furniture company that provides a strategic opportunity to expand the segment of business and receive appropriate benefits.

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УДК 339.187:684
Доц. А.В. Івануса, канд. екон. наук – НЛТУ України;
доц. В.Б. Загорняк, канд. екон. наук – ПВНЗ ІУПР УЕП «КРОК»

Екологічні аспекти формування маркетингової стратегії меблевих підприємств

Представлено основні компоненти маркетингової стратегії меблевих підприємств в контексті еколого-економічних особливостей меблевого виробництва та меблевої продукції. Проведено аналіз особливостей меблевої продукції та екологічних аспектів основних компонентів маркетингової стратегії меблевих підприємств: товари і послуги, місце чи система розподілу, ціна, просування, позиціонування.

Ключові слова: маркетингова стратегія, компоненти маркетингової стратегії, меблі, меблеве підприємство.

UDC 504: 658 *Post-graduate K.R. Khomyk – UNFU*

TRANSFORMATION OF ACCOUNTING AND AUDIT COSTS OF THE AT FORESTRY ENTERPRISES IN CONDITIONS OF ECOLOGICAL ECONOMY

This article deals with some approaches to improve costs accounting. Specifically, proposed to create additional accounts and sub-accounts in accounting with consideration environmental factor. The paper indentifies and determines the modern structure of environmental costs as an important element in the cost of ecological economics.

Keywords: accounting, auditing, costs, environmental costs, transformation, ecological economy, suggestions, improvements.

A characteristic feature of modern economic development of Ukraine is global economic transformations in production based on market relations and ecological economy. Market relations require a revision of the accounting and audit, one of the central elements of which are accounting and audit of expenditures. Current economic conditions require addressing a number of important accounting issues. Specifically, these are the problems of transformation of accounting and auditing in terms of ecological economy. Today, accounting the expenditures in ecological economy is extremely important because it affects the ecological and economic efficiency of management.

The aim of the study is classification generalization and deepening economic knowledge explore current practice of accounting for forest enterprises, development of recommendations to improve accounting and auditing in ecological economy of Ukraine. It is necessary to solve the following problems:

1. To investigate current practice of accounting and auditing in the enterprises and its relevance:
- the requirements of accounting standards;
- the needs of users for accounting information to make information-based decisions;
- the current requirements of the economy.

2. To developed recommendations for improving accounting and auditing of expenditures.

Nowadays, the transformation of accounting expenditures in the ecological economy including the allocation of environmental costs in total costs is of great importance. Environmental costs – a combination of expenses and losses in natural surrounding [1].

A modern structure of environmental costs society in the current economic and legal mechanisms of nature is the following (Fig. 1):

- operating and capital costs of preventive conservation measures;
- economic evaluation of adverse effects of pollution and disturbance components of the environment (economic loss, damage);
- payments for emissions (discharges) of pollutants and waste in the environment;
- payments for use of natural resources;
- penalties for environmental violations and payments in respect of losses;
- the system of compensation payments to the population living in adverse environmental conditions.

With regard to current environmental costs, these should include the following:

- payments for pollution of the surrounding environment and other effects;
- payments under mandatory and voluntary environmental insurance;
- costs of payment services of other organizations, committed by order of the territorial bodies of the environment;
- operating costs associated with the maintenance and operation funds on environmental protection;
- the cost of disposal of environmentally hazardous waste;
- the cost of wastewater treatment;
- other current environmental expenditures.

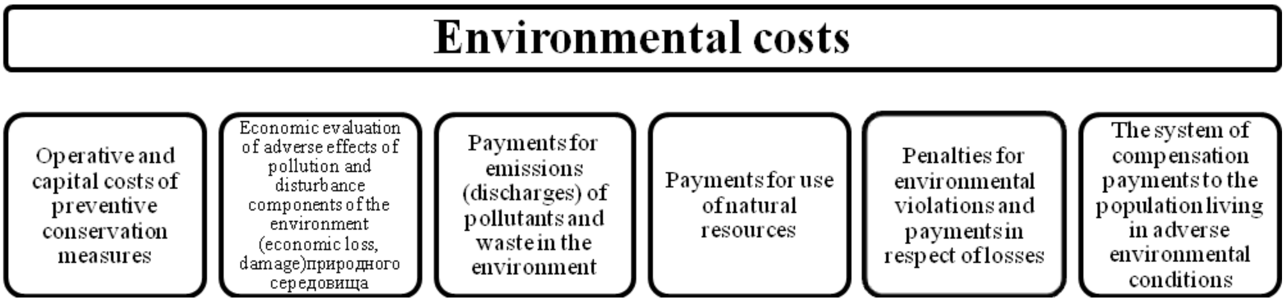

Fig. 1. Structure of environmental costs

In addition, separating the costs of waste management:

- processing waste;
- package waste;
- recycling paper and cardboard waste;
- transportation and rent;
- places used for disposal of garbage;
- removal of special waste.

In general, the separation of expenditures for environmental measures out of general expenditures is rather complex so as nowadays the improvement of environmental conditions is considered to be the main condition of any investment in order to replace or expand capacities.

We should pay attention to the approach of differentiated determination of environmental and economic expenditures for those who use resources of the region according to their marginal utility. In the future it can be the basis for intersectoral ecological balance. This approach is the original one to determine the expenditures of restoring the damaged fixed assets and nature based on the dynamic model of assess and the effects of environmental pollution on objects. The expenditures are treated as depreciation and the method of calculating the required term of objects in environmental conditions is aimed to accelerate depreciation of fixed assets [2]. However, this development can not be applied in practice, because it does not correspond to the requirements of the mandatory organizational regulations on accounting and tax accounting for fixed assets.

Objectively, necessary environmental costs – is one of the fundamental concepts of environmental savings. Their structure is shown in Table 1 [3].

As a result of research has produced the following approaches to the transformation of accounting costs in terms of ecological economics are proposed[4].

- Accounts of company should reflect its relationship to the environment, as well as the impact associated with environmental management costs, risks and responsibilities on the financial condition of the company.
- Investors who make investment decisions should have information about environmental activities and costs associated with environmental management.
- As conservation measures are also the subject of management, managers should identify and reallocate environmental costs so that the products will be properly assessed and investment decisions will be based on real costs and benefits.
- Environmental accounting has become the key to sustainable development based on the principle of ecological effectiveness, while the latter can be measured only in terms of providing accurate information about the environmental cost savings and the impact of economic activity on environment.
- Legislation, banks, investors, the public and the competition (including international) encourage reporting of environmental measures and their effectiveness.

Today the distinction between environmental and other costs is retained, including costs of total production safety, the lack of which complicates the study of these costs and the establishment of their actual efficiency.

Table1. Structure of the environmental costs of society

Group costs and losses	Contents of environmental costs and losses
1	Direct costs of conservation, clean air and water pollution, land and other components of the living environment
2	Expenses for reproduction of quality of natural living environment which are destroyed by destructive changes
3	Losses associated with irreversible negative changes in the natural environment, the quantity and quality of natural resources
4	Losses associated with the need for reserving natural targets of natural objects that could operate and offer real economic benefit
5	Extra costs associated with the development of natural resources in increasingly worse conditions and resources, remote from the centers of direct consumption
6	Increased costs of processing and low-quality secondary raw materials (waste) into marketable products of in order to save conditioned raw
7	Measures to increase reproduction related natural resources, as well as searching and creating substitutes for used non-renewable resources
8	Total expenditures on basic and applied research and design work in the field of natural living environment and natural resources, formal and informal environmental education and training

First of all enterprises should take into account the specific nature of some leading industries (chemical and petrochemical industries, automotive, pharmaceutical, steel and forest industry) to improve cost accounting [4, 5]. It is also necessary to distinguish the actual (past) and planned (future) costs. Entrepreneurs and managers are particularly interested in accounting for planned expenditures, which are not possible without showing the actual costs. Accounting should detect and display the value of externalities (costs) in money form. This problem can be provided by using two different approaches:

- Making adjustments to the traditional accounting system through a more detailed and differentiated mapping environmental aspects of business, including all the costs of environmental protection, as well as changes that caused by them in the balance of the enterprise. This approach can be called differentiation financial statement.
- Reorganization and expansion of accounting, including compiling balance for a more complete reflection of external environmental costs. It means the expansion of the financial statement.

In the first case, the differentiation of traditional accounting to the annual report the aim of which is to better display the concrete forms of ecological management of the property and enterprise profitability. In accounting costs differentiated reflection of environmental costs by types and place is necessary. Calculation of costs for individual products or services can also serve as reflection of costs and turnover due to environmental aspects. Similar computational operations are connected with the general problems of accounting. This approach allows us to find reserves and minimize the costs of environmental protection.

The second approach is reorganizing and expanding the account in order to use it as a tool for active environmental management. Traditional accounting hardly is suited for this purpose. For its reformation new objects into account should be defined, new goals of accounting and other indicators should be formulated. Accounting should fully reflect the possible positive and negative externalities caused by industrial activity [6]. The rational construction of the Plan accounts and clear guidelines for its use play an important role for proper organization of accounting process. In order to improve cost accounting in the profit and loss, account should include items such as: cost (the cost of purchasing environmentally friendly raw materials), depreciation (depreciation of environmental equipment), and other costs (for environmental protection).

Also, within the accounting the cost of production can be isolated idiosyncratic supporting environmental positions. Namely, the cost of training in the field of environmental management, depreciation for the full restoration of basic protected industrial foundations, bank interest on environmental loans, environmental fees, charges and fees, special services (e.g., elimination of waste) [6]. An important direction of the State Strategy for Sustainable Development of Ukraine aimed at a balanced solution of socio-economic problems for the future and continuing favorable environmental quality is the use of an environmental audit as a tool to ensure a favorable ecological climate [6].

Environmental audit interacts with market mechanisms in the economy, serves as protecting the safety of life, and is an environmental and economic policy, environmental management and marketing investment. Environmental audit, according to the law of Ukraine "About Environmental Audit" designed to ensure compliance with legislation about environmental protection facilities in the process of economic and other activities. Environmental audit is documented systematic independent evaluation process of environmental objects, including assembly and objective assessment of the evidence to establish compliance with certain activities, events, conditions, management of the environment and information on these issues with the legislation of Ukraine about environmental protection and other environmental audit criteria [7]. Paper [8] deals with holding regular environmental audit commissioned for forestry production complex leadership at the state level. In addition, we should use a standard agreement inclosing protocol (list of) environmental auditing, environmental passport enterprise.

Particularly important is the implementation of environmental audits in enterprises of forestry sector. It will allow companies to optimize financial costs including environmental factors, prevent the occurrence of losses associated with environmental pollution, to achieve certain environmental benefits, subsidies, taking into account the contribution of enterprises to improve the environment, improve relations with environmental authorities and the population.

Program Audit Company has to plan, establish, implement and comply with the environmental importance of operations, which are being considered, and the results of previous audits. Transforming of expenditures audit is based on the change of the Plan accounts with regard to environmental factors.In particular, it is necessary to introduce additional sub-accounts in category 9. The account 91 "Total expenditures" should expand sub-account "General manufacturing environmental costs." Sub-account "Total environmental costs" should be added to the account 92 "Administrative expenses", and sub-account "Other environmental costs" should be added to the account 94 "Other operating expenses". Auditors should examine and investigate environmental costs during auditing the costs except production expenses and production cost of produced and sold products. In my opinion, the purpose of costs auditing of operating activity is to establish the reliability of the primary data of collection and to write-off transaction costs, including environmental, completeness and timeliness display raw data in summary documents and accounting records, the correct costs accounting of core activities and its compliance with the adopted accounting policy, the reliability of information on the costs given in the reporting entity.

Thus, the proposals regarding the transformation of accounting and auditing of operating expenses will clear organization accounting process for forestry enterprises, significantly improve the efficiency and timeliness of accounting information, to monitor the formation of financial results, and the most important is that it will be a small step for Ukraine's development towards a greener environment, because environmental factor is taken into account.

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УДК 504: 658
Аспір. Х.Р. Хомик – НЛТУ України

Трансформація обліку і аудиту витрат лісогосподарських підприємств в умовах екологізації економіки

Розглянуто певні підходи до вдосконалення обліку витрат підприємства. Зокрема, запропоновано вводити додаткові рахунки і субрахунки при веденні бухгалтерського обліку враховуючи екологічний фактор. Сформульовано визначення і сучасну видову структуру екологічних витрат, як важливого елемента витрат в умовах екологізації економіки.

Ключові слова: облік, аудит, витрати, екологічні витрати, екологізація економіки, трансформація, пропозиції, вдосконалення.

UDC 331.102.344:330.14.133
Senior teacher V. Yakobchuk;
assoc. prof. L. Malyk – UNFU

INTELLECTUAL CAPITAL IN THE ASSESSMENT OF BUSINESS VALUE

Presented in this paper are definitions of the following categories: intellectual property (IP), intellectual capital (IC), intangible assets (IA). An analysis of the assessment of intellectual capital in the value of Ukrainian and foreign companies has been made. Several approaches to improving the ways of the formation and assessment of intellectual capital have been proposed.

Keywords: intellectual property, intellectual capital, intangible assets, firm's value.

Intellectual capital (IC) has always been a major source of maintaining the high status of Ukraine in the international arena, which implies the high level of education, cultural traditions, and scientific-and-industrial potential.

However, the crisis has disrupted the regenerative process in most of enterprises in Ukraine. In order to resume this process, an emphasis should be made by the enterprises on their intangible assets, that is intellectual capital.

The whole world is now in the process of forming the so-called "knowledge society", this being the main way of enhancing the countries competitive ability [2, 3, 11].

In the late 1960s, the industries that were directly related to the production and usage of knowledge came to be known as "knowledge industries", their share in GNP, for example in the USA, ranging from 29 to 34% [11].

All the world's leading countries are placing emphasis on increasing share of intangible assets and hence the share of intellectual constituent in the final output. Thus, the value of intangible assets in the total value of foreign companies makes up 40 to 50% [10]. In the sector of high technologies, the value of intellectual capital is 3 to 5 times as much as the value of their current income, and by 3 to 100 times exceeds the value of conventional tangible assets [8].

Therefore, the Brand is becoming the dominant factor in the assessment of value of a company's assets [15].

The share of intangible assets in the balance sheet of Ukrainian enterprises amounts only to 0.4 – 0.7%. Most often, intangible assets are not accounted at all.

In developed market economies, the indicator of intangible assets assessment and the methods of measuring them are of great scientific and practical importance. A demand arose for specialized audit service as well as for services to assess intellectual capital. To correctly compare the assessment results for different firms, special standards are being developed.

Statistical assessment of intellectual capital at Ukrainian enterprises is carried out on a fragmentary basis [8, 12]. This adds complexity and every so often makes it impossible to do a system analysis of this indicator.

The concept of intellectual capital and its related concept of intellectual property are essential components which identify the new market economy [4, 5, 6].

It should be noted that the relation between the concept of "intellectual capital" acquire a meaning only under conditions of market of market pricing and functioning stock market. Under conditions of the administered price management, intellectual product does not have a value which would be equal to its contribution to the economy. It is important to keep in mind that the effectiveness and value of intellectual capital become determinable and is able to go up only in the context of a certain strategy for the enterprise development; otherwise the available intellectual resources might be of little use. The most successful development of intellectual capital can be found within the channel of purposeful activities as to the development of a new product and a new niche in the commodity market. Moreover, intellectual resource calls for a long-term and systematic approach to its structuring. Occasional efforts such as "brainstorming" conducted by the outside, invited, specialists do not contribute much to the intellectual capital of the given enterprise. At the same time, noncreative and unskilled work done by the enterprise's employees make it impossible to create or use the intellectual capital.

Intellectual capital can often make for the survival of an enterprise under crisis conditions. To do this requires a clear understanding of the very notion of "intellectual capital", its structure, the ways of its evaluation as well as the potential benefits arising from the effective use of this kind of capital.

No proper attention is being given to these issues in Ukraine [8, 13]. Historically, patents, licenses, copyrights, etc. were issued by state bodies, these duties having been performed absolutely inadequately. The country was proud of the large number of invention done; however, the earnings to the treasury were miserable compared to what has been achieved by other industrialized countries. Under present conditions, such attitude to intellectual property presents a threat of severe economic disasters. Intellectual property is a constituent part of National Security [9]. Great efforts have been made, for example in the USA, to attract from everywhere people who are capable to create an intellectual product. A case in point is the USA government's declaration that they are ready to grant entry visas to several hundred thousands of computer programmers.

It should be also pointed out that, so far, Ukraine has taken only first steps toward the solution of the problem of protecting intellectual property.

For comparison: in France, over 200 companies are engaged in the issue of copyright and other related rights. An adequate regulation in the sphere of intellectual property has been in progress there since 1943. In addition to France, similar companies dealing with copyright management are found in Bulgaria, Poland, Estonia and other countries. In Poland, significant changes in the legal sphere concerning protection of industrial and intellectual properties have taken place. The intellectual property right, which became effective in 2001, has received the status of Code.

The intellectual capital category is both new and complex. That is why the literature on economics abounds in significant differences as to the interpretation of this term beginning with "brainpower", "the total knowledge of the enterprise's workforce" and ending with company trademark and assets. These definitions are just general terms with no reference to such categories as "price", "rent", etc., nor has this concept received a clear-cut legal definition. The article of the same name in "Civil Code of Ukraine" does not contain such definition; there is only a mere listing of "subjects" and "objects" of intellectual property [1]. The term IP was first recorded at the foundation of the world Intellectual Property Organization (WIPO); however, this term was not then scientifically defined [9, 16]. From the standpoint of accounting, Intellectual property is treated as company's intangible asset that has a certain market value. Therefore, the company can dispose of this property at their discretion: to lease (to hire out), to put as security for getting a loan to expand their own capital, etc.

That is to say, this product can act both as goods and capital [7].

So, the question is: "How is Intellectual capital to be assessed?"

This problem was first faced by some intellectual, information-intensive, companies in the USA when attracting inward investments to expand their business. The investors were not willing to finance businesses like this, which is business with small volumes of tangible assets stock. This brought up a task of measuring the value of intangible assets of a company, which would create a favorable investment situation.

The main consideration in such measurement is the fact that the value of intangible assets of company is precisely that price which the business rival is not able to receive fully for their product because of a lack of such assets.

At present, there are three legal approaches to the assessment of intellectual capital.

- Cost-based approach. It is used in estimating the value of intangible assets in the event that it is impossible to find an analogue, while the predicted income is not steady (e.g. when assessing the database).
- Comparison approach. It is used in the event that there exists a fairly mature market of intangible assets that are assessed.
- Profitability approach. It is used in assessment of patents, licenses, trademarks, property rights. This is based on the estimation of economic gains associated with earning profits at the expense of intangible assets not recorded in the company's balance sheet and which ensure profitable assets or equity capital greater-than-average size.

As for the comparison approach, it is realized by way of correlation between the market value of stock capital (SC) and the value of capital assets (including depreciation) (VCA). We can state that the difference between these two values IS = SC – VCA will suffice to describe the value of non-material assets of a company.

The cut in the gap between the market and the book values shows the need for taking measures to prevent the IC concept from degradation.

D. Tobin, a Nobel Prize winner in economics, has proposed a more reliable indicator of company's Intellectual Level that the difference between the market capitalization and depreciated value of capital assets. The so-called Tobin's coefficient (q) is the ratio of market object's value to the value of its substitute:

if $q < 1$, that is the object is lower in coast than its substitute, there is no point for the company in investing capital in the other object. And vice versa, it is more profitable to buy a new object if it costs the company a lower price. There is one regularity to observe: high value for the coefficient q and IC represent the value of technological investments and human assets. Beside, the coefficient q can describe the degree of profitableness for the company in the exchange of goods. For example, at $q = 2$ (a market value of the company is twice as much as the value of its hypothetical substitute), the company will gain the most benefit from this kind of property.

The Tobin coefficient, which is the ratio between market value to its renewable value, is employed as the indicator of intellectual capital usage as a whole. For intellectual capital, the value of this coefficient is larger than 1. When the Tobin coefficient is very high, the company is earning extraordinary profits with the use of this kind of assets. All this is evidence for the advantages of intellectual capital. In this respect, q is an indicator of monopoly rent that is the ability of company to gain higher profits due of having something which is not available with other. This can be considered as a perceptible manifestation of the company's IC.

The coefficient q can be calculated both for a company as a whole and also for its individual object of property.

Naturally, the main medium of intellectual capital can be specially selected and trained personnel of the company.

With qualified management at hand, the maximum return on human assets may be 3 times as high as the return on machinery investments.

The studies of how labor efficiency is dependent on education have revealed the following: a 10% rise in education level yields an 8.6% increase in labor efficiency. The same increase in stock capital results in a 3 to 4% increase in labor efficiency.

Therefore, one can now appreciate the topicality of attempts to find reliable ways of measuring the scope of institutional knowledge of employees, their experience and intuition, and the information they mastered.

Thus N. Koba has proposed a procedure for identification of the coefficient of knowledge which helps in determination of the influence of knowledge management on a company's value added.

The absence of perfect procedure for assessment of IC in Ukraine results in the application of indirect indicators (investments in intangible assets, dynamics of the usage of scientific and research-and-engineering works, innovation introduction and innovative activities).

Thus, the share of scientific and research-and-engineering works is not significant in Ukraine (0.9% and it tends to decrease). The innovative activities indicators in Ukraine do not meet the present world's trends: in the industrialized countries like Japan, Germany, these figures are equal to 50-80%, while in Ukraine – 13%, and this also tends to decrease [7].

Therefore, taking into consideration the fact that IC has become a key factor for maximizing business value, it is essential that necessary preconditions should be created in Ukraine for immediate formation and adequate assessment of IC.

This implies, first of all, a state-level support for the formation, application of IC as well as improvement of the normative base, which would allow for correct assessment of IC.

Conclusions. It has become imperative to do the following with respect to IC question:

1. to make necessary changes in Ukraine's labor market;
2. to solve the problem of storage, accumulation, competent application and skillful commercialization of IC [17];
3. to develop the market of information-and-intellectual products;
4. to identify the scope of the subject's rights to make decisions concerning IC;
5. to overcome the „wastefulness syndrome” with the help of IC [19];
6. liberalization of sector-specific legislation [7];
7. to bring the system of IC accounting in Ukraine in accordance with the world's existing practice, etc.

The above measures will contribute to the desired effect of IC application in Ukrainian economy as a whole and in Ukrainian enterprises in particular. This, first of all, means to increase their market value, at the expense of additionally-involved intangible assets, to 15-20% [10], which could give them (to Ukrainian enterprises) an edge in the economic competition. So, an increase in the company market capitalization by way of implementation of „Value Drivers” will make it possible for most companies to get an increase in market price in the range from 50 to 100% within 2 to 5 years' period, this being the main objective of a company in modern society.

The provision 8: „Intangible assets” of the accounting standards adopted by order of Finance Ministry of Ukraine of 18 October, 1999, No. 244 and by Law „Corporate income taxation” of 28 December, 1994, No. 333/94 (with amendments and supplements), which regulate the intangible assets evaluation procedures, does not meet the currently growing requirements.

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УДК 331.102.344:330.14.133 ***Ст. викл. В.М.Якобчук, доц. Л.О. Малик – НЛТУ України***

Інтелектуальний капітал в оцінці вартості підприємств

Розглянуто значення інтелектуального капіталу [ІК], як основного чинника конкурентоздатності держави загалом і окремих підприємств, зокрема проілюстровано. Зрослий акцент на інтелектуальний капітал в загальній вартості іноземних компаній і незначну його частку в балансі управлінських кампаній. Наведено дефініції категорій інтелектуальна власність [ІВ], інтелектуальний капітал, нематеріальні активи [НА]. Проведено аналіз оцінки інтелектуального капіталу у вартості українських і зарубіжних компаній. Запропоновані напрямки вдосконалення формування інтелектуального капіталу.

Ключові слова: інтелектуальна власність, інтелектуальний капітал, нематеріальні активи, вартість компанії

UDC 630.116.11:228.3
Post-graduate N. Koziy;
assoc. prof. I. Kulchytskyy-Zhyhaylo – UNFU

ESTIMATION OF INTERCEPTION LOSS FOR VARIOUS FOREST TYPES

By applying the Gash model, the magnitude of rainfall interception and its components has been estimated for two mixed stands in the Carpathians. The estimated magnitudes agree well with the experimental results. In a red-oak dominated stand, the gross interception loss was 50 mm greater than that in a common-pine dominated stand, which is mostly due to greater evaporation during rainfall events. The forest canopy intercepts part of the rainfall to evaporate in later, thus preventing this part of precipitation from reaching the soil. The interception loss is influenced by the canopy characteristics and meteorological factors, varying within a wide range.

Key words: interception, interception model, precipitation, evaporation, canopy storage capacity, rainfall event.

The study objective is to compare, on the basis of empiric data and the Gash analytical model, the magnitude of interception and its components for various forest types.

The object of the study. The study was carried out at two study plots within the area of the Boryslav forest district – the Drogobych forestry enterprise, compartment 15 (Table 1).

Table 1. Study plot characteristics

Plot No.	Stand composition	Plot area, ha	Age, years	Altitude, a.s.l., m	Volume, m^3/ha
1	50% Pinus sylvestris 30% Fgus sylvatica 20% Abies alba	0.25	57	520	516.06
2	40 % Abies alba 60 % Quercus rubra	0.28	60	490	553.24

The methods of the study and instrumentation. Precipitation was measured by means of precipitation gauges located as follows: 16 plastic gauges, with catch area of 58 cm^2 each [6], were placed at the nodes of a "net" measuring 10x10 m under the stand canopies at the study plots (No. 1 and No. 2). Close by, 3 gauges were placed in a clearing. The catch of the under – canopy gauges were averaged. The samples were taken during the growing season immediately after each rainfall event. In parallel, the duration of rainfall was measured by self-recording rain gauge (pluviograph). For the case when there occurred 2 or 3 rainfall events within the period between sampling, the data were excluded from the investigation. The intensity of each single rainfall was determined according to the measurements of the pluviograph.

Modelling of the interception process (theory). The classical approach to modelling interception of rainfall by the forest canopy, which was proposed by Horton as early as 1919 [3], consists in establishing an empiric dependence between interception and precipitation depth which may be described as $I=\alpha P-\beta$, where I is the interception loss; P is the amount of rainfall falling on the forest canopy; α, β are coefficients of regression. Rutter et al. [4] proposed a physically-based numerical model of the interception process around which Gash [2] and other investigators [1] developed a variety of analytical models. For input parameters, in addition to empiric data on precipitation depth (as with the empiric models), the analytical models employ a number of meteorological parameters (air humidity, temperature, radiation, atmospheric pressure etc.) as well as the forest canopy cover characteristics.

The descriptions of the interception process are Rutter-based models: for the each rain event a fraction *p* of the precipitation *P* (mm) reaches the forest floor directly, the remaining part *(1-p)* touches the canopy and may be temporarily stored (*C*; in mm), evaporated to the atmosphere (*E*, in mm/h) or drained to the forest floor (D; in mm/h) by canopy drip or by stemflow. Stored water will evaporate when the rain is has ceased.

$$I=Ce+Et+P-T \tag{2}$$

where: I is interception (mm); C_e – water storage at the end of the rain event (mm), Et– evaporation during rain (mm), P – precipitation (mm), and T is the sum of througfall and stemflow (mm), which equals rainfall inside the canopy.

Two assumptions have been made in (2): 1) rain events are separated by dry periods long enough to dry the canopy completely and 2) canopy drainage is negligible after the rain has stopped. The storm-based analytical Gash model represents the rainfall as series of discrete storms, during which three phases can be distinguished: a wetting phase during which rainfall P (mm) is less than the value required to saturate the canopy P_s (mm); saturation phase (provided rainfall intensity, *R*, exceed evaporation from the wet canopy, *E*), and a drying phase after rainfall has ceased. Interception is presented as a sum of interception loss during each of these phases. Evaporation from the canopy during the storm is represented by average evaporation rate *E*, the assumption is that the ratio of average evaporation rate over average rainfall intensity E/R is equal for all storms. The forest structure is described in terms of a canopy capacity, S, which is defined as the amount of water left on the canopy in zero evaporation conditions when rainfall and throughfall have ceased and a free throughfall coefficient *p,* which determines the amount of rain which falls directly to the forest floor without touching the canopy (*p* is often assumed equal to one minus the canopy cover). Input parameters of model are: the value required to saturate the canopy P_s, average rainfall evaporation rate from the wet canopy E**;** water canopy capacity *S* та canopy structure parameter *(1-p).* Two method of estimation of *S* and *p*, described in detail in [1], are presented below.

The simple way to simulate water storage is to assume that no water drips from the canopy before the canopy capacity (S) is filled (so-called "waterbox" concept), so $D=0$ when C< S. Based on this concept it is reasonable to divide the scatter plot of I versus T into two parts: a wetting part when P<Ps , (Ps is the precipitation needed to reach saturation, saturation meaning $C \geq S$ in the "waterbox" concept) and a saturated part when $P \geq Ps$. Interception during wetting is then given by:

$$P<Ps: \quad D=0,\ I=(1-p); \tag{3}$$

$$P \geq Ps: \quad I(P)=(1-p-\frac{E}{R})P_s+\frac{E}{R}P \tag{4}$$

Equation (4) was obtained in assuming a constant ratio between E and R during rain. Interception and precipitation can then be plotted for a large number of rain events. A linear regression of the type $I(P)=\alpha P+\beta$ for $P \geq Ps$ results in estimates of $\alpha=\frac{E}{R}$, the ratio of evaporation to rainfall, $\beta=(1-p-\frac{E}{R})P_s=S_{mean}$, the mean water storage capacity (mm). This method is denoted as the 'mean method' in this study, as it is based on a least square fitting of data.

Interception loss calculated according to the analytical Gash model is the sum of the following components: 1) $I = (1 - p)\sum_{j=1}^{m} P_j$ - interception loss for m storms that is insufficient to saturate the canopy (*P<Ps*); 2) $n((1-p)P_s - S)$ - wetting up canopy for n storms *P≥Ps*; 3) $\frac{E}{R}\sum_{j=1}^{n}(P_j - P_s)$ – wet canopy evaporation during n storms *P≥Ps*; 4) nS – evaporation after storms for n storms *P≥Ps*.

Results. The interception loss *I* is computed as the difference between the averaged values for precipitation depth measured in the open and those measured under the forest canopy for each study plot. The studies employed data obtained from the precipitation gauges and pluviograph. A total of 49 rainfall events that occurred during the growing season of 2012 were used for the analysis.

The dependence of interception loss upon precipitation depth is shown in Fig. 1.

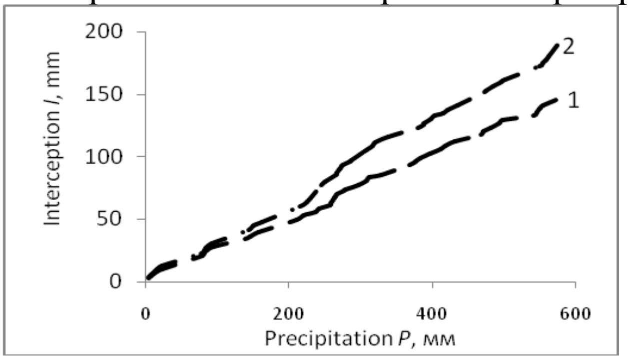
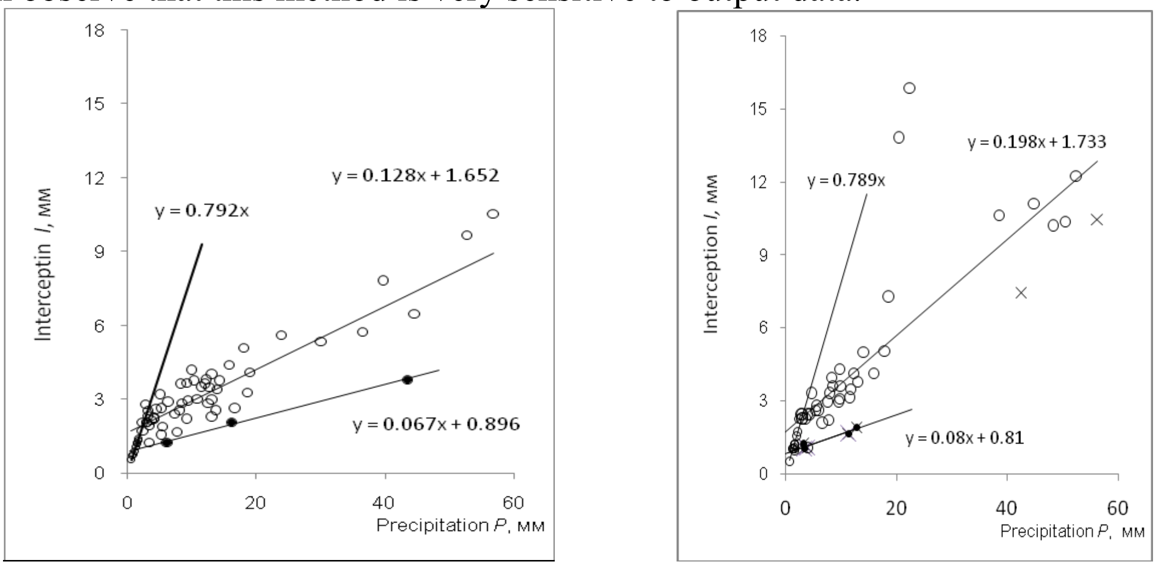


Fig. 1. Cumulative measured interception versus the precipitation in study plot No.1 (1) and study plot No.2 (2)

The canopy storage capacity S was computed by employing two methods based and demonstrated on the graphs for empiric dependence of interception I upon throughfall T. The first method – the Leyton method – (a minimal method) consists in passing the regression line on the graph *I=I(P)* through some selected points representing the period of heavy rainfalls with minimum interception loss. The free term of regression is unknown quantity. It should be noted that the selection of these very points is essential. The selection for the regression of points denoted as “x” (Fig. 2, b) gives a value for S=-0.69, which is nonsense; that is why they were excluded from the construction. Thus, we can observe that this method is very sensitive to output data.



a) b)

Fig. 2. Interception versus precipitation for all rain events in
a) study plot No. 1; b) study plot No. 2

For the data of study plot No.2, the regression line passes through the points denoted as "•" (Fig. 2, a) giving S= 0.81 mm. The minimal method gives S= 0.9 mm for plot No.1. These values are considered [1] to be too small to construct the regression line by employing this method since only the points of the canopy drip onset are to be used for this purpose rather than the points of saturation, as "waterbox" conception maintains.

Another method of determining the canopy storage capacity *S*, a "mean method", is relatively dependent on the selection of point Ps (the precipitation depth necessary for full canopy saturation). Ps was calculated simultaneously with *S* by iteration method.

On the graph for experimentally established interception loss dependence upon rainfall magnitude, we can distinguish between two groups of rainfall events: "light" rainfall ($P<Ps$) and "heavy" rainfall ($P\geq Ps$); however, determining the demarcation line between them (that is Ps) is somewhat of subjective character. In order to mitigate the subjective approach, the calculation of Ps and S was done by iteration method: a)first, we visually choose point $Ps^{(0)}$ as initial approximation of unknown quantity *Ps*; b) second, by means of point $Ps^{(0)}$, we divide the array of rainfall magnitude data into 2 groups: $P<Ps^{(0)}$ and $P\geq Ps^{(0)}$; c) third, we identify $Ps^{(1)}$ as the abscissa of intercept of the data regression lines of each group, and then compare $Ps^{(1)}$ with the points of each of the groups; d) in the case that the derived value of $Ps^{(1)}$ in the array of precipitation depth is extreme in one of the groups (that is between the obtained point and the end point in the group there are no other points), we will take the obtained value for the unknown quantity, that is $Ps=Ps^{(1)}$, thus completing the search. If not so, then the obtained point becomes a new point of division into groups, that is $Ps^{(0)}=Ps^{(1)}$, and we will turn again to item b) and so on until we obtain the value for *Ps*.

For example, in selecting a precipitation depth of 3 mm in plot No. 2 as the initial point of division, we obtain, at the first iteration, a value of 2.88 mm for the new point of division. Then, at the second iteration we obtain 2.93 mm, which we take for the unknown quantity, that is Ps=2.93 mm. It should be noted that we have obtained actually the same regression equations for "heavy" rainfalls I=0.198P+1.7333 irrespective of which rainfall from the range 2.5-3.1 we incorporated into "heavy" rainfalls.

The value for S, calculated by the "mean method", for plot No. 2 is equal to S=1.73 mm, which is much greater than the value determined by the first method. The free through fall coefficient obtained from the regression equation for rainfalls P<2.93 is equal to p=0.79. For plot No. 1, the following results have been obtained by the root-mean-square method: S=1.65 mm, Ps=2.49, P=0.79.

The intensity of rainfalls during the study period varied within a wide range between 0.24 and 8.16 mm/h at a mean intensity being 1.91 mm/h.

Out of the gross precipitation of 573.62 mm that fell on plot No. 1, a 11.72 mm precipitation fell out as 9 "light" rainfalls of magnitude less than 2.49 mm and a 561.9 mm precipitation fell out as 40 "heavy" rainfalls. Out of the gross precipitation of 594.16 mm that fell on plot No. 2, the total of "light" rainfall magnitude made up 18.79 mm (including 12 rainfall events of magnitude up to 2.93 mm), while the total of heavy rainfalls made up 575.37 mm (including 37 rainfall events).

The results of estimating interception components based on the Gash analytical model are given in Table 2. To verify the structure of interception loss, one should have experimental investigations data on the amount of evaporation for different heights of the canopy. However, the values obtained by other authors for similar stands [1, 2] are in agreement with our results.

Table 2. Modelled results of the canopy interception loss components in the study forests (in mm)

Component of interception loss	Study plot No 1	Study plot No 2
For storms insufficient to saturate the canopy ($P<P_s$)	9.0	14.8
For storms ($P\geq P_s$)	141.2	185.7
Wetting up canopy	10.7	19.4
Wet canopy evaporation during storms	64.5	102.3
Evaporation after storms	66.0	64.0
Total	150.2	200.5

Conclusions. The calculations performed by using the Gash analytical model show the total interception loss at study plot No. 1 to be 150.2 mm, and 200.5 mm for study plot No. 2. The significant difference (50.3 mm) in the amount of intercepted and evaporated precipitation at the study plots is noteworthy. The experimental data (Fig. 1) show values of 145.5 mm and 196.2 mm, respectively. The simulated magnitude of interception loss is greater than the experimental data by no more than 3.5%. The smaller proportion of interception loss at study plot No. 1 is attributed to a significant share of common pine in the stand composition, as was indicated by M. Voronkov [5].

The analysis made for the interception loss during the growing season of interest shows that the main distinction between the interception of rainfall at the study plots No. 1 and No. 2is the difference in evaporation during rainfall events: for study plot No. it made up 75.2 mm, while for study plot No. 2 – 121.7 mm. These components are of decisive importance for both plots (50.1% and 60.6% of the gross loss, respectively). Obviously, the character of leaf area of the forest canopy at study plot No. 2 is more favorable for evaporation during rainfall events than that of study plot No. 1.

After rainfall has ceased, evaporation at both plots is practically the same: 66 mm and 64 mm, which is supported by the canopy storage capacity magnitudes obtained for both plots: S1=1.65 mm, and S2=1.73 mm.

Thus, the estimates made by using analytical model provide a realistic presentation of the interception processes and are in agreement with experimental results.

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УДК 630.116.11:228.3
Аспір. Н.І. Козій,
доц. І.Є. Кульчицький-Жигайло, канд. с.-г. наук – НЛТУ України

Оцінка параметрів інтерцепції для лісів різної структури

Для двох змішаних насаджень у Карпатах з використанням моделі Геша розраховано величину інтерцепції дощів та її складових частин. Розраховані величини добре узгоджуються з експериментальними. У насадженні з переважанням дуба червоного сумарна інтерцепція на 50 мм більша, ніж у насадженні з переважанням сосни звичайної у основному за рахунок більшого випаровування під час дощу.

Ключові слова: перехоплення, модель перехоплення, опади, випаровування, ємність затримання наметом.

ДО ВІДОМА АВТОРІВ СТАТЕЙ

При підготовці статей для міжвідомчого науково-технічного збірника "**Лісове господарство, лісова, паперова і деревообробна промисловість"** радимо авторам дотримуватись таких рекомендацій.

Автор поданої до друку статті повинен чітко уявити коло читачів, на яке він розраховує. Рекомендуємо дотримуватись деяких загальних правил побудови науково-технічної статті: чітко і зрозуміло сформулювати постановку задачі; доступно викласти методику її розв'язання; зробити висновки науковцям або дати практичні рекомендації виробничникам.

Наукова праця повинна містити необхідні характеристики описаних конструкцій чи схем, але в ній не має бути ні зайвого опису історії питання, ні відомих з підручників ілюстрацій, даних, математичних викладок.

Текст статті обсягом 5-20 сторінок необхідно подавати українською чи будь-якою іншою мовою, друкувати на папері формату А4 за допомогою комп'ютера у редакторі MS Word (шрифт – Times New Roman, розмір – 14 points, рядки – через 1.5 інтервали, поля – 2 см по периметру) без присвоєння жодних стилів і оформляти в такій послідовності. На початку статті **ОБОВ'ЯЗКОВО** проставляється індекс УДК (Універсальної десяткової класифікації), в заголовку українською мовою вказуються: вчене звання, ініціали і прізвище автора (або авторів), науковий ступінь, скорочена назва закладу, в якому виконана робота, назва статті, анотація (500 знаків) та ключові слова. Далі – англійською мовою: ініціали і прізвище автора (або авторів), скорочена назва закладу, в якому виконана робота, назва статті, анотація та ключові слова.

Сторінки рукопису нумеруються, а на полях олівцем вказуються місця ілюстрацій і таблиць, якщо останні додаються до статті на окремих аркушах. Особливу увагу необхідно звернути на акуратний набір формул, індексів і показників, з використанням можливостей редактора MS Equation.

При підготовці рукопису необхідно користуватися науково-технічними термінами відповідно до діючих стандартів на термінологію, наведений матеріал не повинен дублювати таблиці. Скорочення слів, імен, назв у тексті статті не допускаються. Можливе використання тільки загальноприйнятих скорочень - мір (тільки після цифр), хімічних, фізичних і математичних величин. Назви установ, підприємств, марки механізмів і т.д., що згадуються в тексті статті вперше, необхідно писати повністю (вказуючи в дужках скорочену назву); надалі ця назва може зустрічатися у скороченому вигляді.

У таблицях необхідно точно вказувати одиниці фізичних величин, у назвах граф слова скорочувати небажано. Таблиці необхідно виконувати переважно вздовж листа з максимальною насиченістю інформації в рядках. Надто громіздких таблиць складати не рекомендується.

Ілюстрації (фотографії та рисунки) до статті подаються в одному примірнику. Фотографії повинні бути контрастні, розміром не менше 9x12 см, рисунки розміром не більше стандартного листка, виконані чорною тушшю пером на якісному папері. Допускається подання рисунків у форматі *.cdr (редактор CorelDRAW), у форматі *.tif або *.jpg (редактор PhotoShop, 300 dpi, b/w або Grayscale) чи оформлених у середовищі MS Excel. У тексті статті посилання на ілюстрації беруться в круглі дужки, позиції на рисунках розташовуються за годинниковою стрілкою і повинні відповідати наведеним у тексті. Окремо подані ілюстрації на зворотній стороні нумеруються і підписуються олівцем.

При посиланні в тексті статті на роботи інших авторів у квадратних дужках вказують номер позиції списку літератури, яка подається в кінці статті. Список літератури оформляється згідно з вимогами і правилами складання бібліографічного опису документа. У випадку наведення цитати необхідно вказати, звідки вона взята (автор, назва роботи, номер тому, рік видання, сторінки).

У кінці статті додаються такі матеріали: **прізвища та ініціали авторів, назва статті; заява зі вказуванням для кожного автора вченого звання та наукового ступеня, посади, повної та скороченої назви закладу, де виконана робота, службової чи домашньої адреси, номери телефонів, E-mail, прізвища авторів для листування.** Окрім того, необхідно подати витяг з протоколу засідання кафедри про можливість публікації статті, експертний висновок, дві рецензії - внутрішню і зовнішню. Також вказується кількість примірників збірника, які автор хотів би отримати з опублікованою його статтею.

Старанно вивірений текст статті підписується автором, проставляється дата відправлення чи подання. Редакція може повернути авторові неохайно оформлену статтю, має право проводити редакційні виправлення. До редакції надсилається (приноситься) один роздрукований примірник статті та CD-диск з її текстом. Авторові (авторам) однієї статті видається один збірник з публікацією.

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тел. роб. 238-45-04; моб. 067-79-12-522;
e-mail: gaida@e-mail.ua; e-mail: vmmax@ukr.net; e-mail: f-wood-ind@ukr.net
http://www.FFPWI.NLTU.edu.ua

Ліс. госп-во, ліс., папер. і деревооб. пром-сть : міжвід. наук.-техн. зб. – Львів: НЛТУ України. – 2012, вип. 38. – 188 с.

Збірник науково-технічних праць

ЛІСОВЕ ГОСПОДАРСТВО, ЛІСОВА, ПАПЕРОВА І ДЕРЕВООБРОБНА ПРОМИСЛОВІСТЬ

Міжвідомчий
науково-технічний збірник

виходить з 1964 р.

ВИПУСК 38

Літературний редактор : В.В. Дудок
Редагування іноземних мов : В.В. Лентяков
Комп'ютерне макетування : С.В. Гайда

Електронна версія наукового фахового видання знаходиться на депозитарному зберіганні у Національній бібліотеці України ім. В.І. Вернадського

Підписано до друку 27.12.12. Формат 60×84/16
Папір офсетний. Гарнітура Times. Друк офсетний
Умов. друк. арк. 10,93. Умов. фарб. відб. 11,16
Наклад 250 прим. Зам. № 903/2012

Свідоцтво про державну реєстрацію друкованого засобу масової інформації
(Серія КВ, № 11890-761ПР від 26.10.2006 р.)

Згідно з переліком №19, «Лісове господарство, лісова, паперова і деревообробна промисловість» належить до наукових фахових видань України, в яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора і кандидата технічних наук за такими напрямами: технічні науки, сільськогосподарські науки, економічні науки (Додаток до постанови президії ВАК України від 15.02.2007 р. № 1-05/2)

Віддруковано з готових оригіналів.
ПП «Карен», вул. П. Мирного, 24.
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